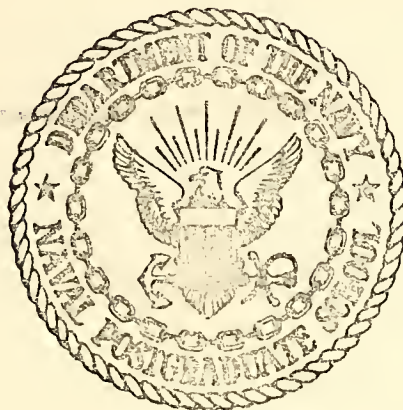AUTOMATIC FREQUENCY TRACKING AND AN
APPLICATION OF TARGET TRACKING
USING PASSIVE DOPPLER TECHNIQUES

Dennis Wayne Hurst

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AUTOMATIC FREQUENCY TRACKING AND
AN APPLICATION OF TARGET FIXING
USING PASSIVE DOPPLER TECHNIQUES

by

Dennis Wayne Hurst

September 1974

Thesis Advisor: H. A. Titus

T 162490

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Automatic Frequency Tracking and An Application of Target Fixing Using Passive Doppler Techniques		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; Sept 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dennis Wayne Hurst		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1974
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A software package was developed to provide the inputs for a passive single-sensor acoustic tracker. This required a computation of sound propagation velocity and resolving high-resolution frequency information from raw acoustic data. A selected frequency was then automatically tracked from an up-doppler to a down-doppler condition. This frequency information coupled with associated bearing information was then used to provide continuous target fixes.

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73
(Page 1)   S/N 0102-014-6601 |

1

Automatic Frequency Tracking and an
Application of Target Tracking
Using Passive Doppler Techniques

by

Dennis Wayne Hurst
Lieutenant, United States Navy
B. E. E., Auburn University, 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING ACOUSTICS

from the

NAVAL POSTGRADUATE SCHOOL
September 1974

ABSTRACT

A software package was developed to provide the inputs for a passive single-sensor acoustic tracker. This required a computation of sound propagation velocity and resolving high-resolution frequency information from raw acoustic data. A selected frequency was then automatically tracked from an up-doppler to a down-doppler condition. This frequency information coupled with associated bearing information was then used to provide continuous target fixes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE

I. INTRODUCTION

Continuous fixing of an underwater sound source by passive means has traditionally been carried out by using multiple sensors. Single sensor fixing requires varying power coefficients, frequencies, and/or bearing changes and usually produces an estimated position with an accuracy that varies greatly with the type of sensor and processing utilized and the skill of the evaluator. An accurate single sensor track would be advantageous in that positional errors could be minimized with only one buoy or array required, providing greater flexibility in that a series of sensors are not required to be monitored, and a decrease in buoy expenditures could be expected. To provide the necessary frequency data, a software package was developed that computed the sound propagation velocity, detected a discrete frequency signal and automatically tracked that signal from a full up-doppler through a full down-doppler situation. This frequency output combined with associated bearing information, and a value for the sound propagation speed with an estimate of the speed of the target provides sufficient input data for single sensor fixing.

II. THE TRACKING PROBLEM

A. STATEMENT OF THE PROBLEM

Chapter 3 of [1] developes the required input quantities for passive, single-sensor fixing. These values are an estimate of target speed, the velocity of sound propagation in the medium, the doppler shifted frequency and a bearing from the sensor to the target. The estimate of target speed would have to be determined by tactical considerations at the time and location of signal acquisition, i.e., target transiting or on-station, signal strength, detection ranges, etc. The bearing would be provided by a standard DIFAR buoy or an array. In this problem the standard deviation of bearing measurement noise was varied from 5° to 30°. Methods of providing the sound propagation velocity and the doppler shifted frequency were then devised.

B. DEVELOPING THE INPUTS

Equation 1.1. of [2] provides a good approximation of sound speed in sea water as a function of temperature, salinity and pressure. It is repeated here as equation 1.

$$c(T, S, z)=1449+4.62T-.054T^2+1.3(S-35)+.017z \qquad (1)$$

where c is in meters per second, T is in degrees centigrade, S is in parts per thousand, and z is in meters. Converting this equation so that c is in yards per second, T is in degrees Farenheit and depth is in feet, yields equation 2.

11

$$c(T, S, z) = 1476.1 + 3.97T - .018T^2 + 1.42(S - 35) + .0057z \qquad (2)$$

If the target depth is known, the median depth of the target and hydro-phone should be used. Otherwise, use the hydrophone depth. Salinity would normally be set to 35ppt unless operating in water of a known different salinity. The resultant output from this equation would be set equal to the velocity of sound propagation, VP, and used as an input value to the target tracker program.

The frequency requirements called for a high-resolution value which dictated a relatively long time window. A twenty second window was used which resulted in a .05Hz FFT resolution. This resolution was further enhanced by interpolation using the relative values of the power coefficients associated with the discrete frequency being tracked. In order to maintain contact on the same discrete frequency line, a frequency tracker algorithm was devised. This provided the necessary frequency data for the target tracker program.

III.   SOFTWARE IMPLEMENTATION

A.   SOUND SPEED

This process was a simple matter of implementing the equation for sound speed in seawater, equation 2.   Providing the chosen depth, observed temperature, and salinity results in a best estimate of the actual sound speed in the operating area.   Updating this value would be necessary as the operating area or environmental conditions changed.

B.   FREQUENCY

1.   Parameters for Frequency Computations

In order to provide realistic frequency inputs, a magnetic tape was obtained that contained analog, raw acoustic signals representing ambient noise plus an underwater sound emitter with various discrete frequencies.   The doppler shift of a discrete frequency signal is directly proportional to the rest frequency of the signal.   Thus doppler shift measurements are more easily obtained from higher frequencies. However, signal attenuation in the medium is much higher at higher frequencies.   At present, frequencies in the 150Hz to 300Hz range will yield usable values with realizable frequency resolution measurements. The highest signal frequency of interest determines the required sampling rate of the data.   The sampling rate and the time window length determine the required dimension of the data input matrix.   With these

considerations in mind, the following parameters were chosen in digitizing the data:

> 'Sampling Rate of 512 samples/second yields Nyquist frequency of 256Hz;
> Input data low-pass filtered to 250Hz to prevent aliasing errors;
> Time record length of 20 seconds for FFT resolution of .05 Hz/Bin;
> Hanning window function applied in time domain to reduce sidelobes associated with rectangular data windows.

2. Power Spectrum

With the above chosen data parameters, the input matrix to the POWER Subroutine[3] was dimensioned to 20,480 bins. This corresponds to two bins per data point (1 cosine term and 1 sine term for 10,240 data points) or 10,240 Complex Fourier coefficients. The real data values were loaded into the odd (cosine or real) bins and zero's were provided for the even (sine or imaginary) bins. On return from the FFT Subroutine [6] to the POWER Subroutine, the cosine term is squared and added to its associated sine term squared thus representing the power at some discrete frequency. This discrete frequency is an integer multiple of the FFT processing resolution (the reciprocal of the time record length). The first bin, $Y(1)$, contains the zero frequency power coefficient, the second bin contains the .05 Hz power coefficient, and so on in .05 Hz steps. Thus bins $Y(1)$ through $Y(5001)$ now contained the power coefficients from zero to 250 Hz.

---

[*]Subroutine STATS and POWER were written by Arfman, J. F., Jr., and were adapted for use in this program.

3.   Search Window and Background Noise Suppression

With over five thousand power coefficients available for track-
ing, it is convenient to limit the range of search to those that offer the
best data for doppler tracking.   A signal having favorable characteristics
is first identified, i.e., frequency above 100 to 150 Hz, apparently
stable on a one Hz resolution processor, and of sufficient strength to
maintain a favorable signal-to-noise ratio for a majority of the time.
Then a search window is designated by the adjustable parameters FL
and SRBW, where FL is the lower frequency limit of the search window
and SRBW is the search window bandwidth.   Both parameters must be
some integer multiple of the FFT resolution and would usually be kept
at whole numbers for convenience.   The total number of power coefficients
in the search window would equal N=20(SRBW) and are designated YA(1) to
YA(N).

Ideally when the frequency to be tracked (FTRK) has been iden-
tified, FL and SRBW should be chosen such that FTRK is equal to FL
plus (1/2)SRBW and SRBW is as large as is reasonable to keep the ratio
of signal power in the window to the total power in the window much less
than one.   If $\sum_{K=1}^{L} YA(K) \ll \sum_{J=1}^{M} YA(J)$ for L signal bins and M noise
bins with L+M=N, then the summation as I goes from one to N of YA(I)/N
is a reasonable approximation of the ambient noise level around FTRK [4],
[5].   This calculation is performed and set equal to YNOIS.   Then YNOIS,
or some function of it dependent on the signal-to-noise ratio, is sub-
tracted from each power coefficient in the search window.   Under the

15

assumption that the noise power spectrum is constant (white noise) within SRBW, only the signal power spectrum remains in the window.

4. Frequency Tracking to Follow the Doppler Shift

The frequency selected to be tracked will be the strongest signal in the search window when the first transform is computed. The bin number of that signal is saved as TBIN(JJ). In each succeeding transform the strongest signal (largest coefficient) in the search window is designated TBIN(JJ) and is compared to TBIN(JJ-1). A bin shift greater than 10 is determined to be a new or different discrete signal. The new power coefficients around the last center bin are then examined for discrete signal energy. The maximum value found would be con- sidered the signal energy being tracked if its bin number is equal to the last center bin number plus or minus 1, and its magnitude is greater than a chosen threshold minimum. In this problem this value was set to three times the ambient noise value. If the maximum coefficient found is more than one bin from the last center bin, the old center bin is examined. If its coefficient is larger than at least one of its sidelobe bin values and at least half as large as the maximum found and larger than the chosen threshold minimum value, the old signal bin is con- sidered to still contain the signal being tracked. If any of these test fail, the new maximum found is compared to the chosen minimum value. If the new maximum is larger, it is accepted as the signal being tracked; if not the contact is considered lost. Figure 1 possibly clarifies the above process.

16

BNSHF > 10 → LOAD NEW POWER COEFFICIENTS OF BINS AROUND TBIN(JJ-1) AND FIND NEW MAXIMUM COEFFICIENT. RESET TBIN(JJ) TO NEW VALUE AND COMPUTE NEW BNSHF.

BNSHF ≤ 1 → MAX COEFF > THMIN → (F) CONTACT LOST

(T)

MAX COEFF IS SIGNAL BEING TRACKED

1 < BNSHF ≤ 10 → CHECK NEW COEFF OF TBIN(JJ-1)

$COEFF(TBIN(JJ-1)) > COEFF((TBIN(JJ-1))\pm 1)$ F

(T)

$COEFF(TBIN(JJ-1) \geq (COEFF(TBIN(JJ))) \cdot 1/2$ F

(T)

$COEFF(TBIN(JJ-1)) > THMIN$ T

(F)

OLD TBIN CONTAINS SIGNAL TO TRACK

$COEFF(TBIN(JJ)) > THMIN$ T / F

BIN SHIFT = BNSHF = TBIN(JJ) - TBIN(JJ-1)
THMIN = A CHOSEN THRESHOLD MINIMUM VALUE

FIGURE 1. FREQUENCY TRACKER DECISION FLOW.

17

Once the bin containing the largest portion of the signal energy being tracked has been established, the frequency of that signal is refined by computing the first moment of the three bin power "hump" around it. If the detected signal is an integer multiple of the FFT resolution, adjacent bin spill over will be minimum and the refining calculation would make no correction to the frequency of the bin associated with the maximum power. When the detected signal is not an integer multiple of the FFT resolution the refining calculation adjusts the frequency to a mid-resolution value corresponding to the first moment of the hump. See Figure 2. The frequency corresponding to bin number K is stored in the YL matrix as YL(K). The frequency refining equation used was

$$FTRK(JJ)=YL(K)+RESOL*(YA(K+1)-YA(K-1))/(YA(K+1)+YA(K)+YA(K-1)) \tag{3}$$

where

FTRK=the discrete frequency being tracked,

RESOL=the resolution of the FFT processing,

YA(M)=the power coefficient of the Mth bin.

Letting YL(K)=220.25Hz and using the sample values from figure 2,

$$FTRK(JJ) = 220.250Hz + .05Hz \cdot \left(\frac{1-4}{1+7+4} \right)$$

$$= 220.250Hz + .05Hz \cdot (-.25)$$

$$= 220.250Hz - .0125Hz$$

$$= 220.2375Hz$$

$$220.238Hz \text{ (rounded)}$$
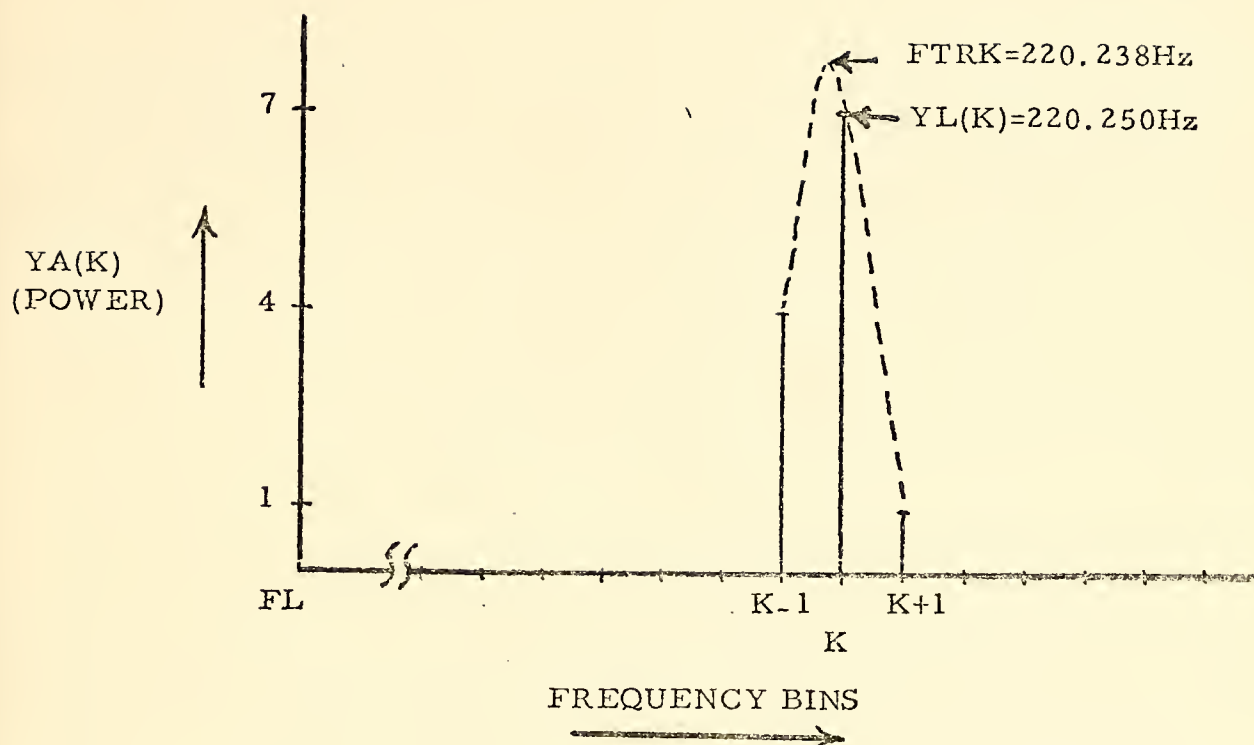
FIGURE 2. RESOLVING MID-RESOLUTION FREQUENCIES WHEN THE DETECTED SIGNAL IS NOT AN INTEGER MULTIPLE OF THE FFT RESOLUTION.

Without this calculation the returned value of the frequency being tracked would have been 220.250Hz. A five bin computation was found to offer no significant improvement over the three bin computation due to the increased probability of noise or adjacent discrete signal influence.

C. DESIGNATING PROBLEM VALUES

In computing the sound propagation speed for the following examples, nominal values were used because the true values were not available. Values used were:

$$\text{Temperature} = 48^{\circ}\text{F}$$
$$\text{Depth} \qquad = 60 \text{ ft}$$
$$\text{Salinity} \qquad = 35 \text{ ppt}$$

The sound emitter on the data tape appeared to make a slow turn into the buoy for the first 4 minutes of the tape and then maintain a constant course at a speed of approximately 4.5 knots. The closest-point-of-approach (CPA) to the hydrophone was approximately 300 to 700 yards and 20 minutes of data was utilized with CPA at about the 11 to 12 minute point on the tape. A 20 Hz search window bandwidth was used with several different lower frequency limits on the window. It was found that one transform per minute comfortably contained the tracked frequencies within the 21 bin tracking window in all cases for a slow-moving, near-field emitter.

D. DATA OUTPUT

1. Run 1 (See Table 1)

With FL set to 40 Hz and SRBW at 20 Hz, the rest frequency of the tracked signal was approximately 50.13 Hz. The total doppler shift was only 0.15 Hz and was too low to provide good tracking data.

2. Run 2 (See Table 2)

For this run FL was set to 220 Hz with SRBW still at 20 Hz. Two strong discrete frequency signals were within the search window bandwidth, one's rest frequency at 233.87 Hz and the other at 223.22Hz. The maximum power coefficient changed between these two signals several times. In the initial transform the tracker locked on to the lower of the two frequencies and a continuous track was maintained even though the signal faded out and then came back. This run gave the frequency tracker a good check-out in that (a) the maximum coefficient in the search window had considerable variations between discrete signals (b) a noise spike occurred in the tracker window at time=430 (FILE=220) and (c) the tracked signal faded completely out at time=1090 (FILE=550) and was regained one minute later. The total doppler shift was approximately 0.6 Hz and provided good data for doppler tracking. The computer output for this run is included in this report in its entirety.

3. Run 3 (See Table 3)

For this run FL was set to 225 Hz and SRBW remained at 20 Hz. The only significant signal in the search window was the 233.87 Hz signal

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	204	155/66	50.155
70.0	205	1759/38	50.190
130.0	205	1619/59	50.185
190.0	205	2001/54	50.203
250.0	205	1620/39	50.180
310.0	205	1527/49	50.192
370.0	204	878/40	50.197
430.0	205	247/42	50.151
490.0	205	9320/78	50.178
550.0	205	13280/68	50.191
610.0	204	56746/254	50.168
670.0	203	38878/144	50.105
730.0	203	42170/187	50.085
790.0	203	47640/227	50.081
850.0	202	6941/55	50.060
910.0	202	9654/71	50.063
970.0	202	18841/125	50.053
1030.0	202	17558/111	50.057
1090.0	202	17546/104	50.054
1150.0	202	14377/87	50.050

Rest Frequency approximately 50.13 Hz

TABLE I.
FREQUENCY TRACKER OUTPUT WITH FL= 50 Hz, SRBW=20 Hz.

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	70	69/6	223.437
70.0	71	112/5	223.481
130.0	71	61/5	223.495
190.0	72	52/5	223.556
250.0	71	254/6	223.489
310.0	70	218/6	223.473
370.0	69	490/9	223.420
430.0	69	64/8	223.407
490.0	70	743/24	223.434
550.0	71	2131/41	223.488
610.0	69	10429/68	223.396
670.0	62	4795/50	223.063
730.0	60	2554/26	222.960
790.0	61	2119/16	222.995
850.0	60	322/14	222.938
910.0	59	245/10	222.882
970.0	59	60/4	222.898
1030.0	59	112/6	222.886
1090.0	60	12/5	Lost Track
1150.0	59	115/5	222.901

Rest Frequency approximately 223.22 Hz

TABLE II.

FREQUENCY TRACKER OUTPUT WITH FL=220 Hz, SRBW=20 Hz.

23

Time (seconds)	Center Bin	Ratio: Signal/Noise	Frequency Tracked
10.0	183	61/4	234.100
70.0	184	42/4	234.151
130.0	185	21/4	234.193
190.0	185	77/5	234.224
250.0	184	167/5	234.169
310.0	184	160/5	234.163
370.0	183	829/7	234.102
430.0	184	708/8	234.144
490.0	184	3295/19	234.132
550.0	184	4824/32	234.130
610.0	183	4669/30	234.079
670.0	176	6049/29	233.756
730.0	174	906/13	233.644
790.0	174	766/7	233.634
850.0	172	1082/11	233.563
910.0	172	1020/8	233.558
970.0	172	27/4	233.563
1030.0	172	357/5	233.545
1090.0	172	135/5	233.530
1150.0	171	23/5	233.525

Rest Frequency approximately 233.87 Hz

TABLE III.
FREQUENCY TRACKER OUTPUT WITH FL=225 Hz, SRBW=20 Hz.

and this was tracked with only a minimal amount of decision require-ments around CPA. The total doppler shift was approximately 0.65 Hz and provided good data for doppler tracking.

E. TARGET TRACKING

Since no bearing information was available corresponding to the frequency data, the IBM 360 Computer was used to generate simulated real time bearings. This was accomplished by programming a pseudo "true track" into the computer so that the target speed and the CPA time were matched as well as possible. The initial starting position was X=500 yards, Y=-1050 yards at time T(1)=190 seconds. The heading and speed used were 90 degrees and 4.5 knots where zero degrees corresponds to the positive X axis. The computer then computed "true bearings" to the target and added random noise values of a programmed standard deviation, SA, to these values. Thus the true track plotted by the computer is only a best estimate of the targets relative position from the buoy.

The X-Y Filter developed by Mitschang [1] was used to process the data and develop the target track. To initialize the filter and commence tracking, the measured bearing must have changed by at least three standard deviations of the measurement noise and the doppler shifted frequency must have decreased from its value at the start of the initializa-tion process. A modification to the filter was attempted so that while initializing, an increasing frequency would be detected as a maneuvering

target. Time, bearing, and frequency values occurring with the maximum frequency detected would then be retained as the initial values to be used when the bearing shift and non-increasing frequency criteria were again satisfied. This would delay the start of the tracking process but would prevent data from a maneuvering target being used to initialize the state equations based on a constant heading, constant speed target. However, indexing problems were encountered and were not resolved in time to include the modification in this report.

The following difference equations developed in Chapter 3 of [1] were used to compute the initial range, heading, and rest frequency of the target.

$$R = -(VP \cdot DELF \cdot DELT)/(f(last) \cdot (DEL\theta)^2 \quad) \qquad (4)$$

$$\theta si = \theta ave - 180 - arcsin((-VP \cdot DELF)/(f(last) \cdot DEL\theta \cdot Vsi)) \qquad (5)$$

$$F0i = Fave [1 - (vsi/VP)\cos(\theta si - \theta ave)] \qquad (6)$$

where

  VP   = speed of sound propagation

  DELF   = doppler shift of the frequency

  DELT   = time required to meet initialization criteria

  f(last) = last frequency measured for initialization

  DELθ = change in bearing from sensor to target

  θsi   = initial estimate of target heading

  θave = average bearing for the initialization period

  Vsi   = initial estimate of target speed

F0i   =initial estimate of the rest frequency

Fave   =average frequency for the initialization period

Then based on a constant heading, constant speed target, the initial

filter state equations are:

$$X(1) \quad =X \text{ position} = R \cos \theta_{ave} \tag{7}$$

$$X(2) \quad =X \text{ velocity} = V_{si} \cos \theta_{si} \tag{8}$$

$$X(3) \quad =Y \text{ position} = R \sin \theta_{ave} \tag{9}$$

$$X(4) \quad =Y \text{ velocity} = V_{si} \sin \theta_{si} \tag{10}$$

$$X(5) \quad =\text{Rest frequency} = F0i \tag{11}$$

The initial covariance matrix values are computed by the "direct

method" developed in Chapter 4 of [1] and an extended Kalman filtering

technique was used to refine the estimates of the target's position,

heading, speed, and rest frequency as the problem progresses.

Since the target was maneuvering for the first four minutes of the

tape, initialization of the target tracker was commenced at time

$T(4)=190$ seconds, with the values from Table 3 as input data. The

average initialization time, AVKJ, varied with the standard deviation of

the bearing measurement noise, SA. This time varied from about 4

minutes for SA=5 degrees to about 8 minutes for SA=30 degrees.

IV. RESULTS OBTAINED FROM REAL FREQUENCY INPUTS

Once the frequency tracker has locked on to a stable but doppler shifted frequency, the inputs required of the operator are an estimate of the rest frequency, F0, and an estimate of the target's speed, AVSK. These are "priming" values used in computing the initial heading of the target and affect the ultimate accuracy of the computed track. A third variable affecting the initialization is the standard deviation of the bearing error, SA. As SA increases, the filter takes longer to start tracking and has more data on which to base its original estimates.

The program was run for various combinations of the three variables F0, AVSK, and SA. The true value for F0 was approximately 233.87 Hz and for AVSK was 4.5 knots. An estimated F0 greater than the detected frequency causes a "down-doppler" solution for the initial course. Conversely an estimate of F0 less than the detected frequency results in an "up-doppler" solution for the initial course. Each combination of variables was looped so that one hundred runs were made with that set of inputs and the averaged filtered positions were plotted. The "+" symbol on each plot represents the computed position of the target at time T(1) plus one-half of the initialization period. The range is computed by Equation (4) and the bearing is the average bearing for the initialization period. The true points from which the noisy bearing measurements

28

were made are plotted with the symbol "*". Averaged filter positions

are plotted with an "X". The ascending order of precedence on each

plot is +, *, X. Figures 3 through 24 show the performance of the system

with real, high resolution frequencies as inputs. F(DET) signifies

initial frequency detected.
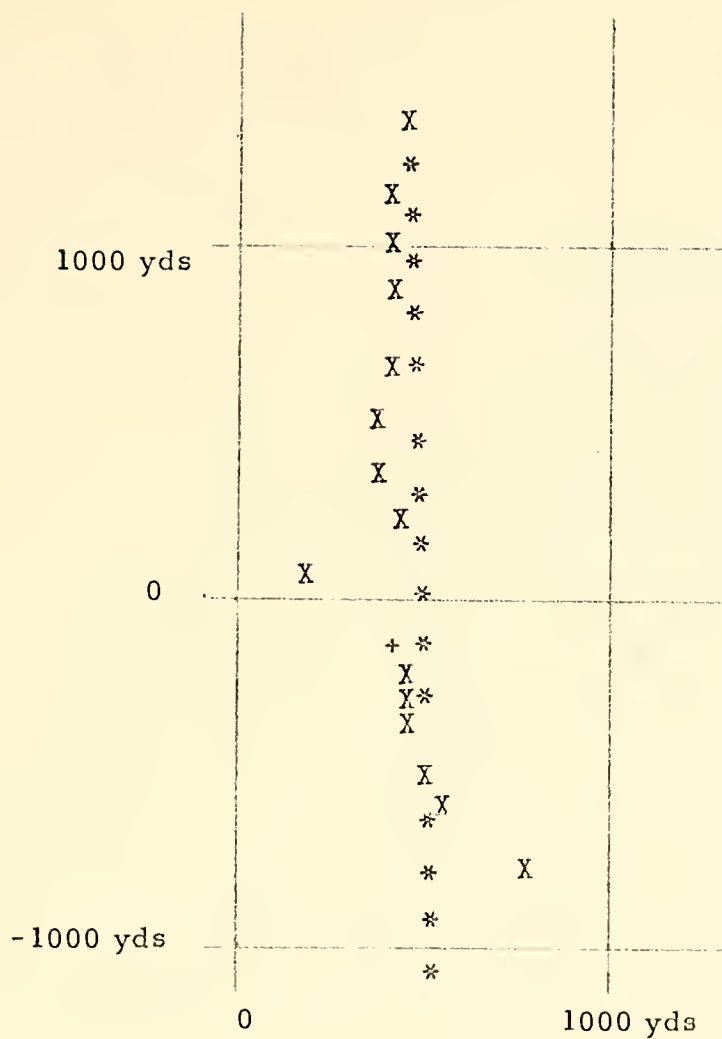
FIGURE 3.   FILTER OUTPUT WITH TRUE FO AND AVSK INPUTS, ZERO BEARING ERROR, AND TEN MINUTE INITIALIZATION PERIOD.   FIFTH TRUE POINT AND FINAL TRUE POINT SUPPRESSED BY FILTER OUTPUT POSITION

30
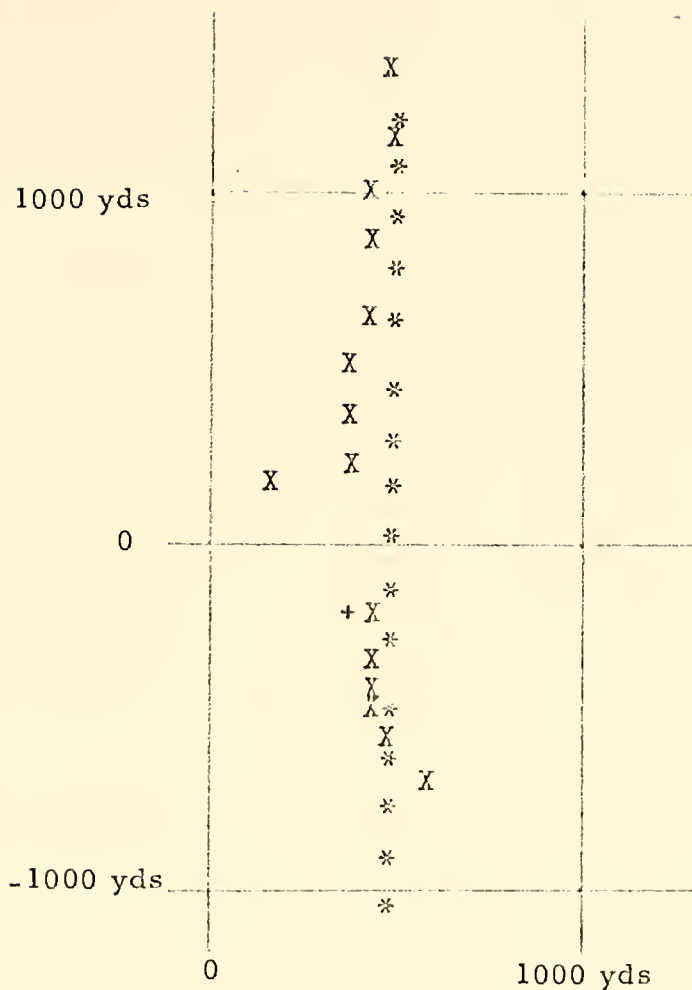
FIGURE 4.   FILTER OUTPUT FOR EST. FO $\leqq$ F(DET), EST.
AVSK $\approx$ TRUE AVSK, AND SA = 30°.   FINAL TRUE
POINT SUPPRESSED BY FILTER OUTPUT FINAL
POSITION.
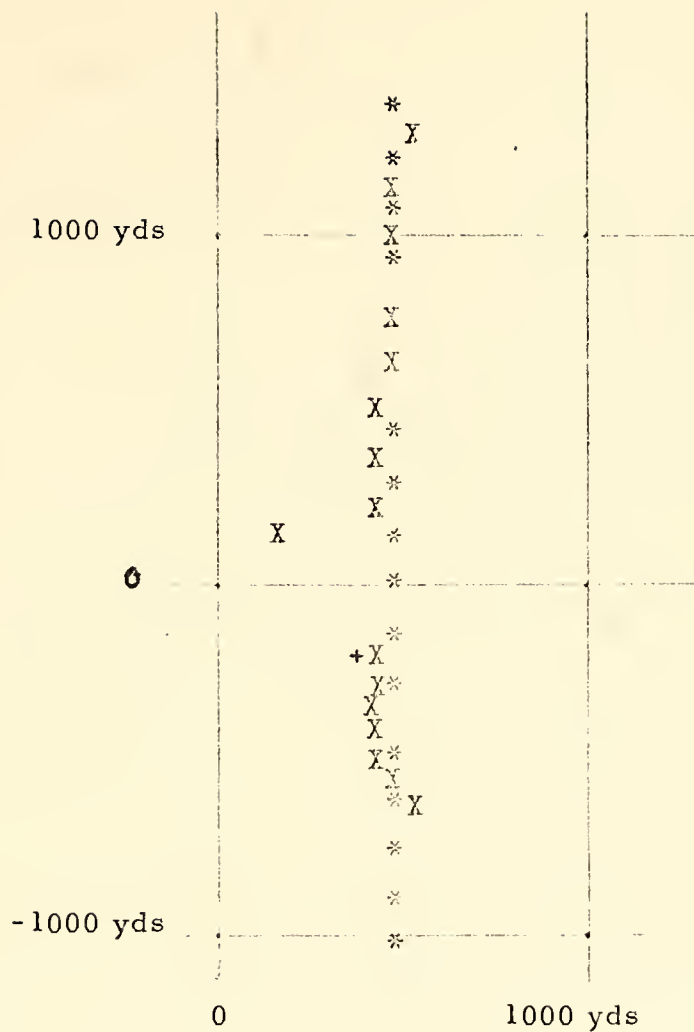
FIGURE 5. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN
F (D E T), EST. AVSK < TRUE AVSK, and SA = 30°. 12th
and 13th TRUE POINTS SUPPRESSED BY FILTER OUTPUTS
13th and 14th POINTS.
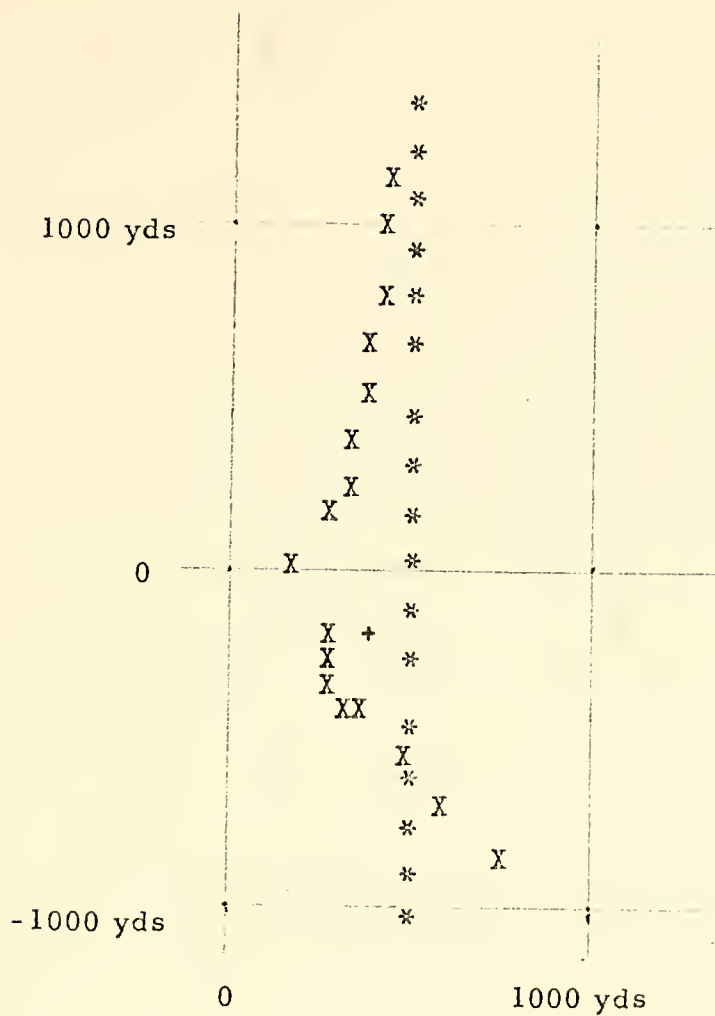
FIGURE 6.   FILTER OUTPUT FOR EST. FO $\leq$ F(D E T), EST. AVSK >
TRUE AVSK, AND SA = 30°.
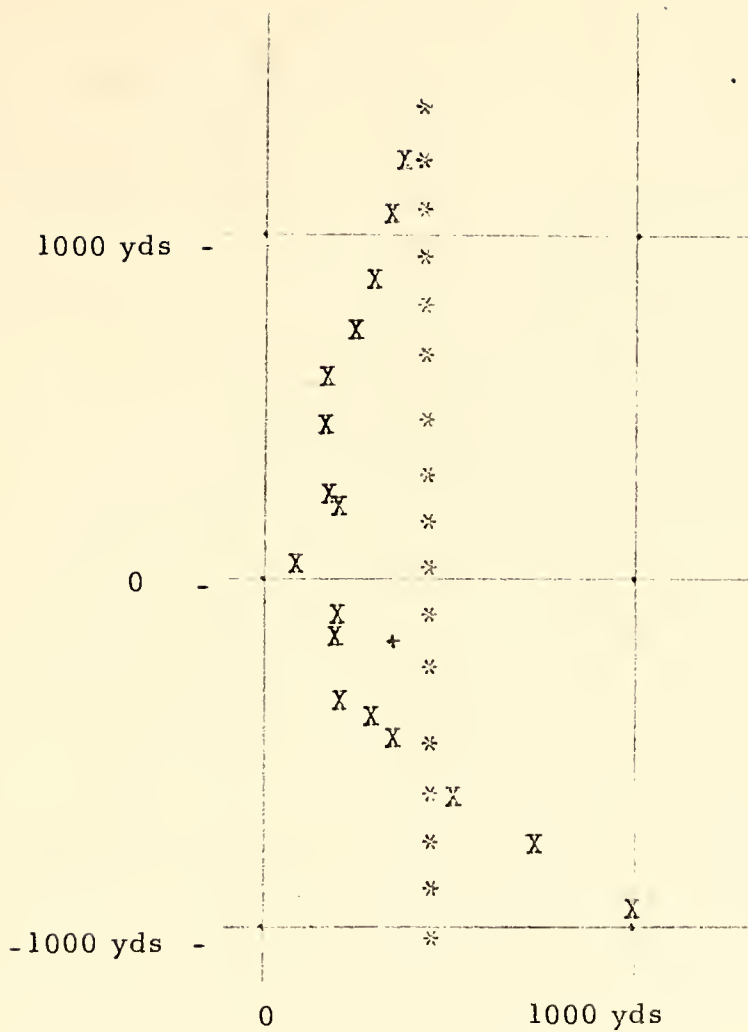
FIGURE 7. FILTER OUTPUT FOR EST. FO> F(DET), EST. AVSK>
TRUE AVSK SA = 30°.
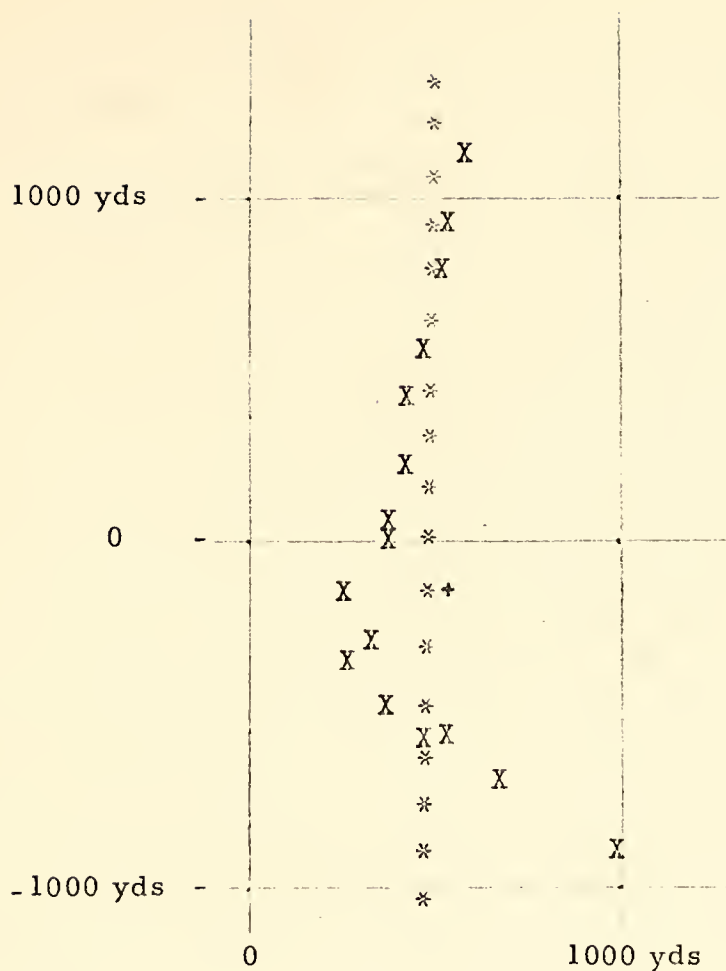
FIGURE 8. FILTER OUTPUT FOR EST. FO $\leq$ F(DET), EST. AVSK>
TRUE AVSK BY 90 PERCENT, SA = 30°.
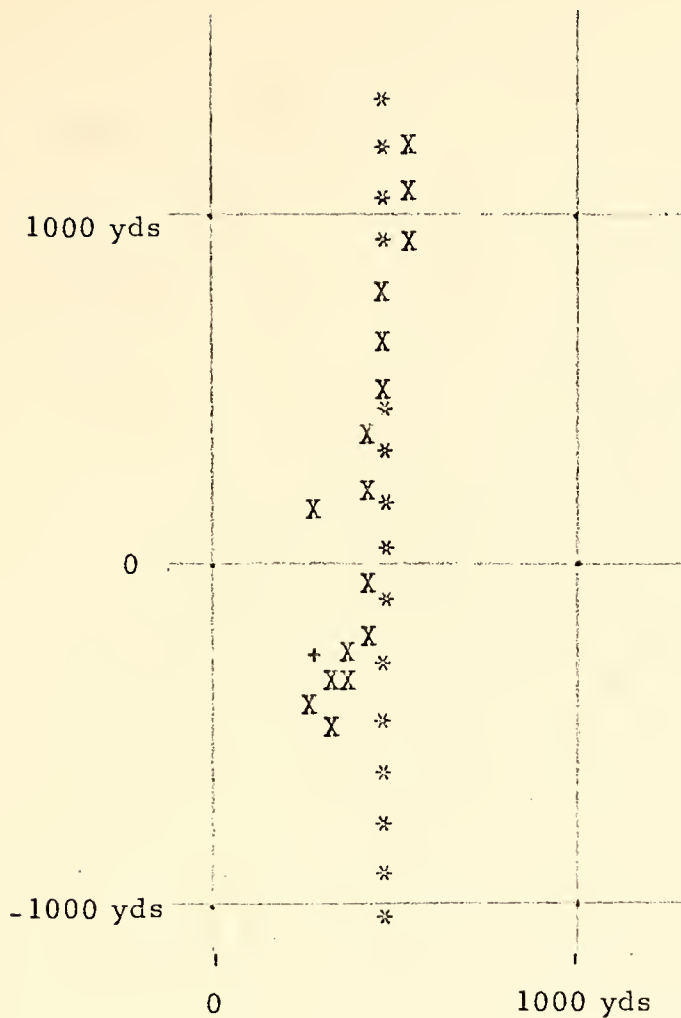
FIGURE 9.   FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
THAN F(DET), EST. AVSK < TRUE AVSK, AND
SA = 15°.   12th and 13th TRUE POINTS SUPPRESSED
BY 13th and 14th FILTER OUTPUT POINTS.
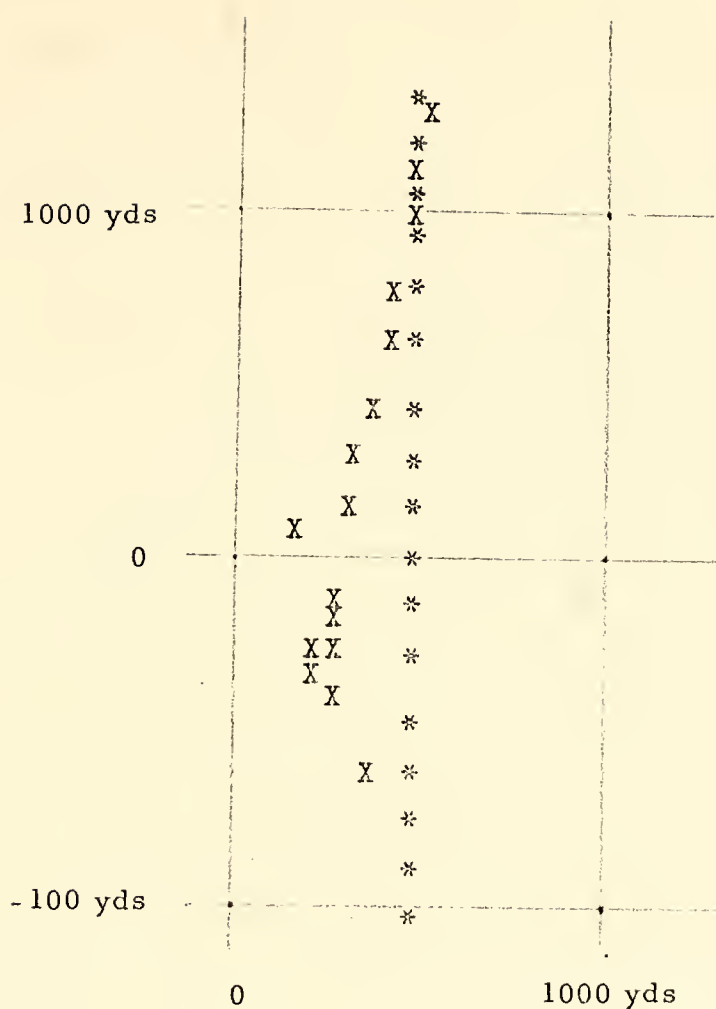
FIGURE 10. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
THAN F(D ET)', EST. AVSK $\approx$ TRUE AVSK, AND SA =
15°.
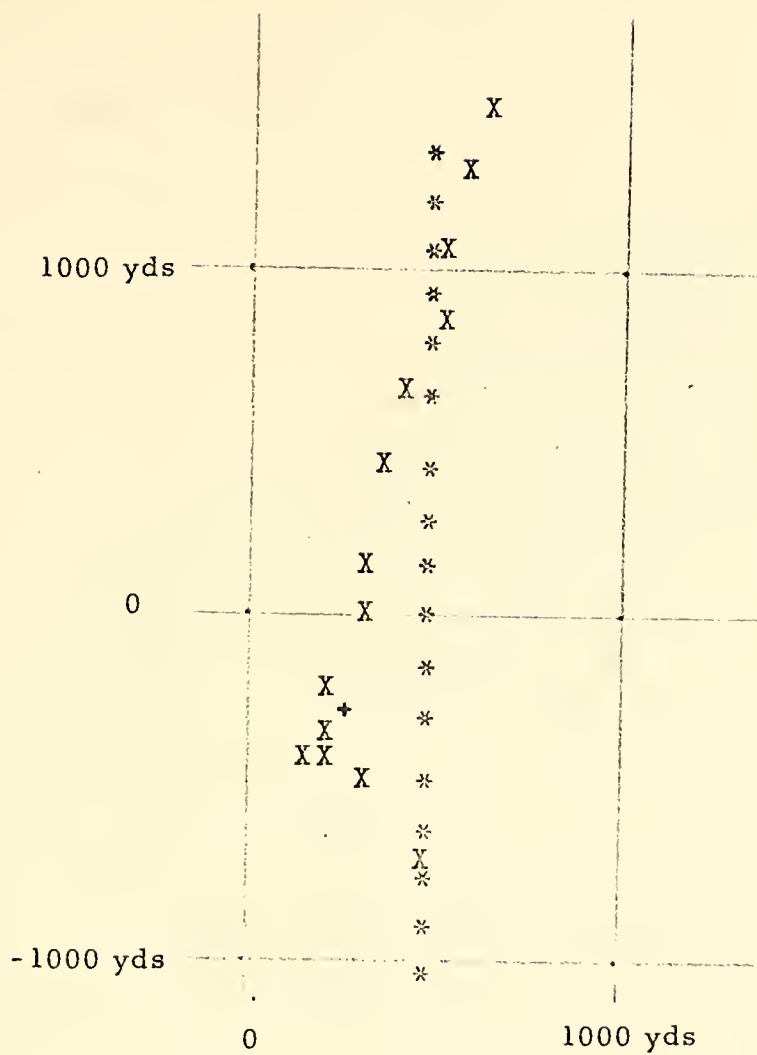
FIGURE 11. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
           THAN F (DET),EST. AVSK > TRUE AVSK, AND SA =
           15°.
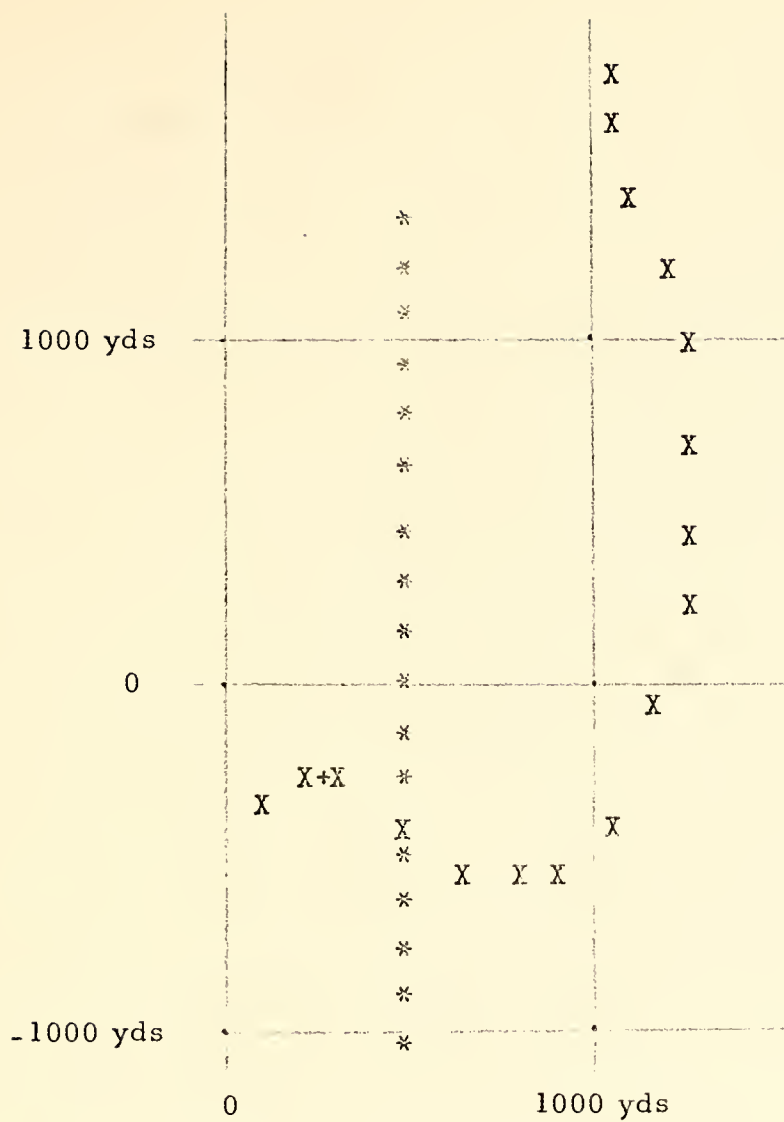
FIGURE 12. FILTER OUTPUT FOR EST. FO > F(DET), EST.
AVSK > TRUE AVSK, SA = 15°.
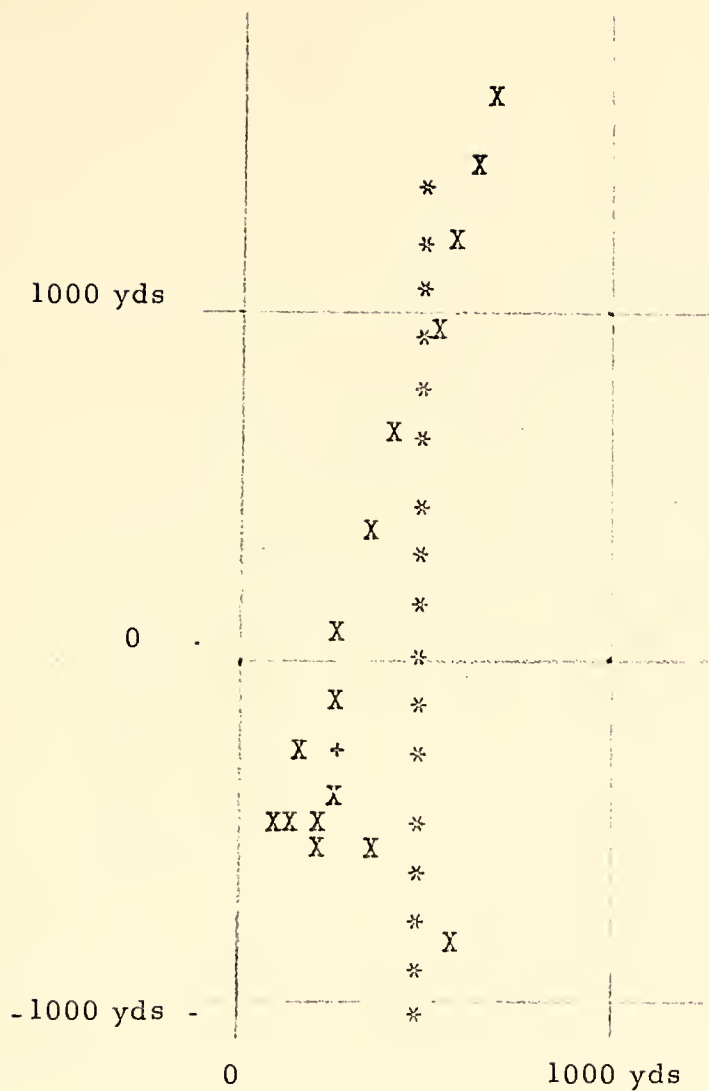
FIGURE 13. FILTER OUTPUT FOR EST. FO ⇐ F(DET), EST.
AVSK ⟩ TRUE AVSK, SA = 15°.
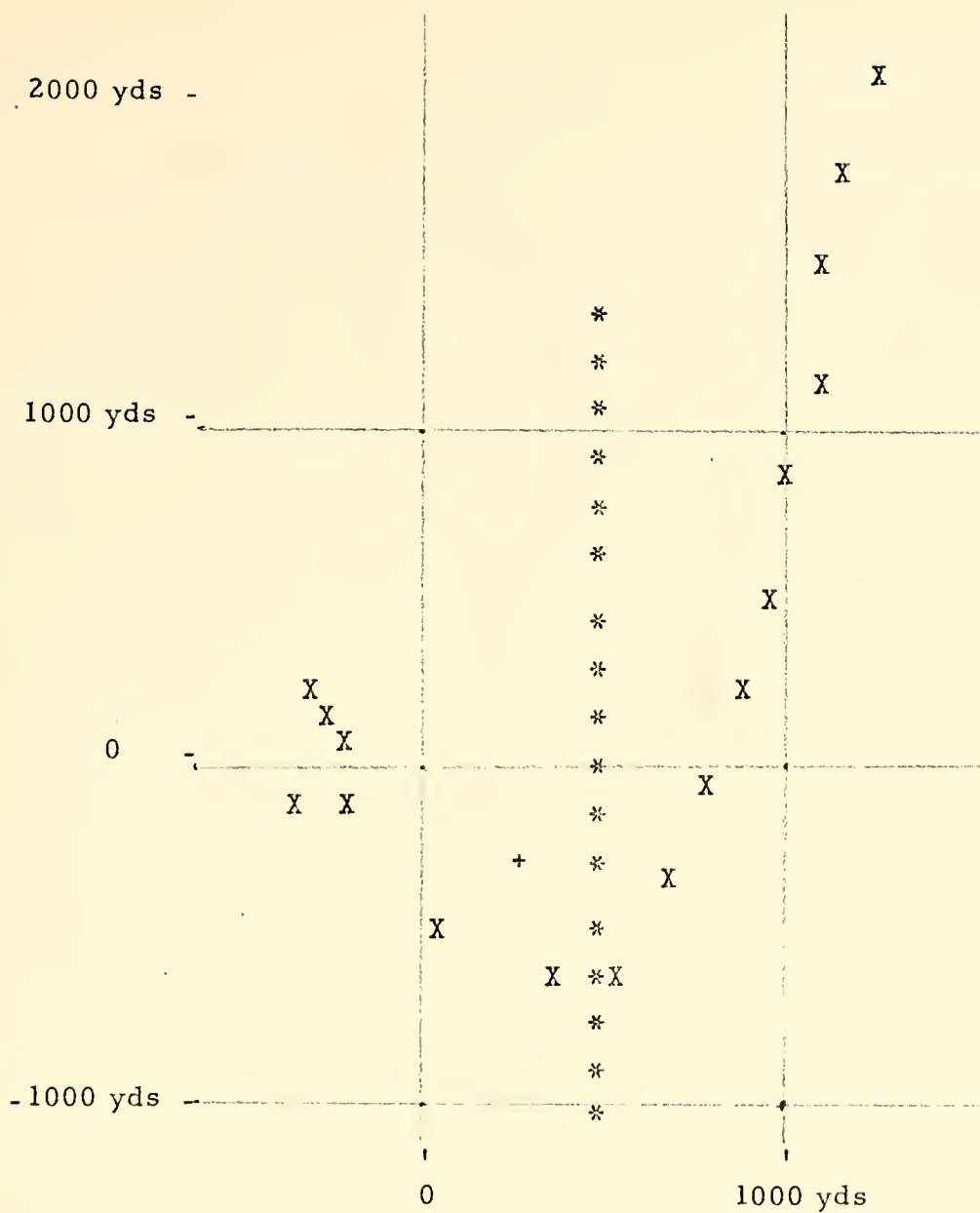
FIGURE 14. FILTER OUTPUT FOR EST. FO $>$ F(DET), EST.
AVSK $>$ TRUE AVSK, SA = 15°.
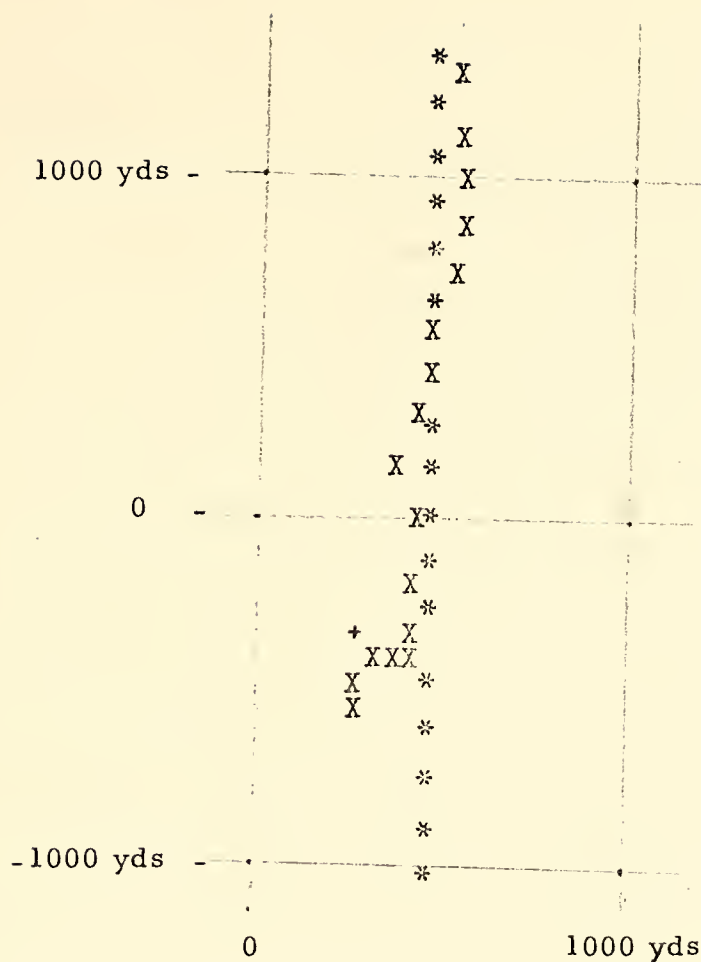
FIGURE 15. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
THAN F(DET), EST. AVSK< TRUE AVSK, AND
SA = 10°. 11th TRUE POINT SUPPRESSED BY 11th
FILTER OUTPUT POSITION.
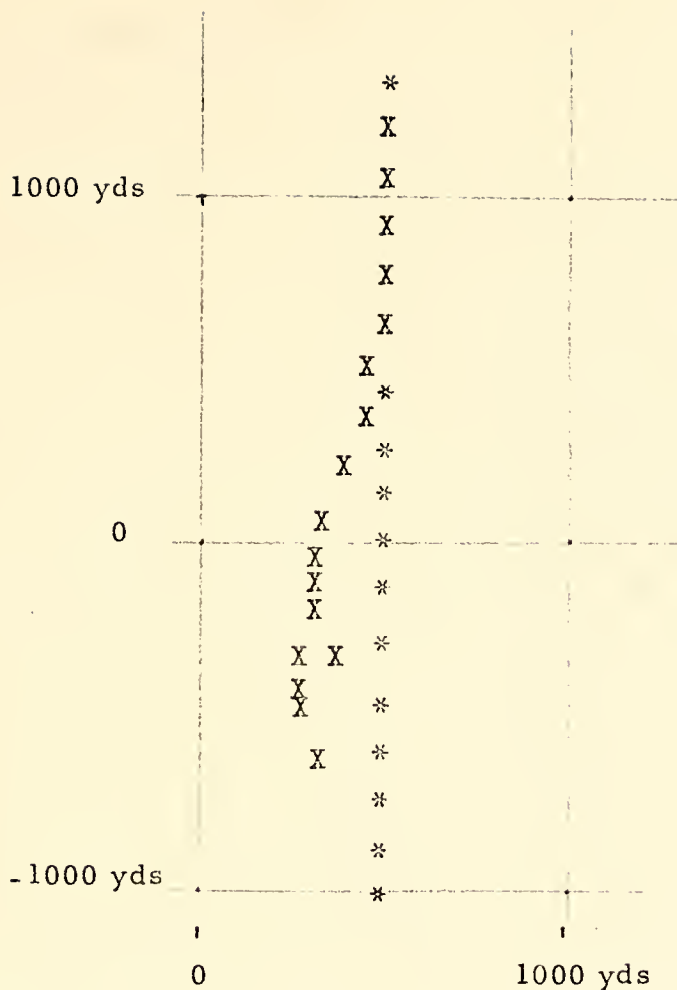
FIGURE 16. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER THAN F(DET), EST. AVSK $\approx$ TRUE AVSK, AND SA = 10°. 12th THROUGH 16th TRUE POINTS SUPPRESSED BY 13th THROUGH 17th FILTER OUTPUT POSITIONS.
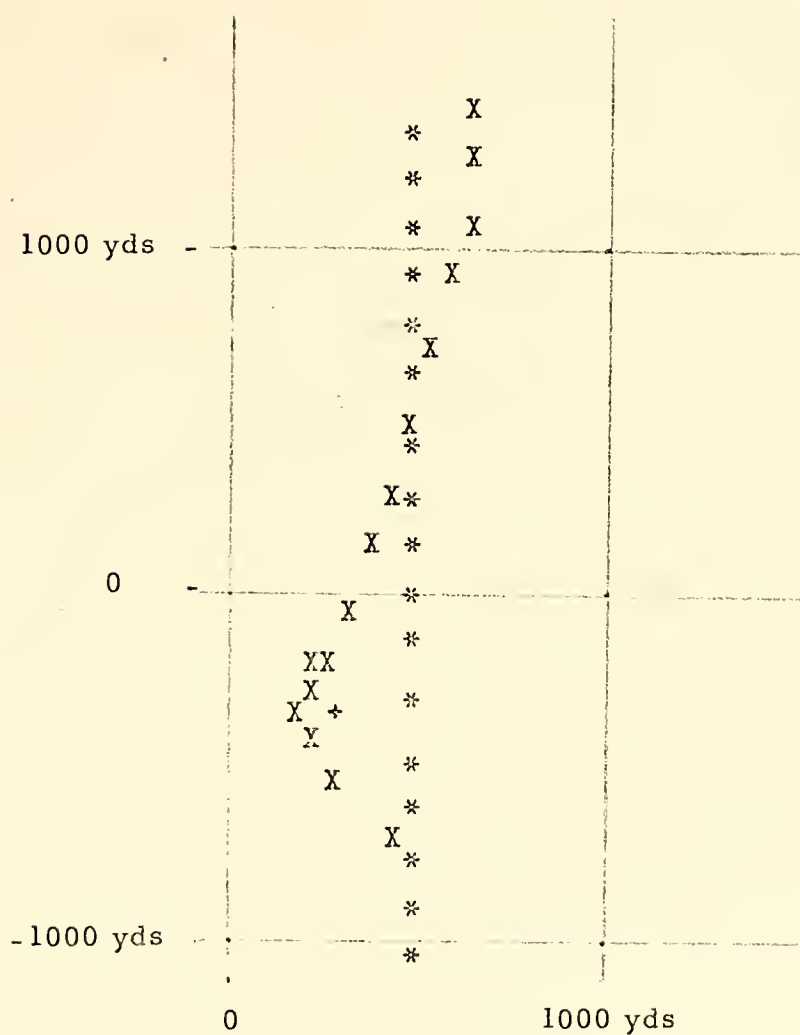
FIGURE 17. FILTER OUTPUT FOR EST. FO$<$ F(DET),
           EST. AVSK$>$ TRUE AVSK, SA = 10°.
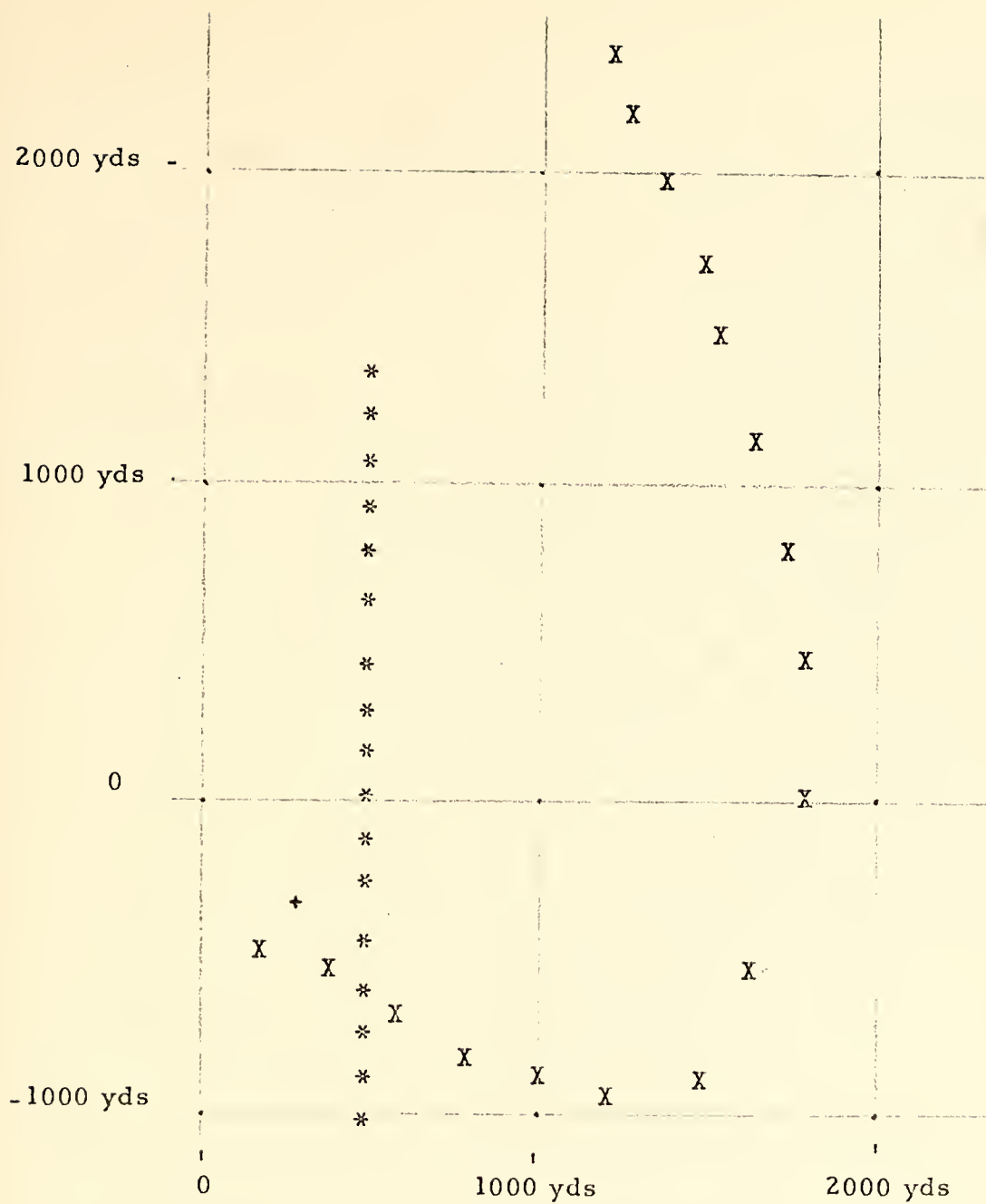
FIGURE 18. FILTER OUTPUT FOR EST. FO > F(DET),
EST. AVSK > TRUE AVSK, SA = 10°.
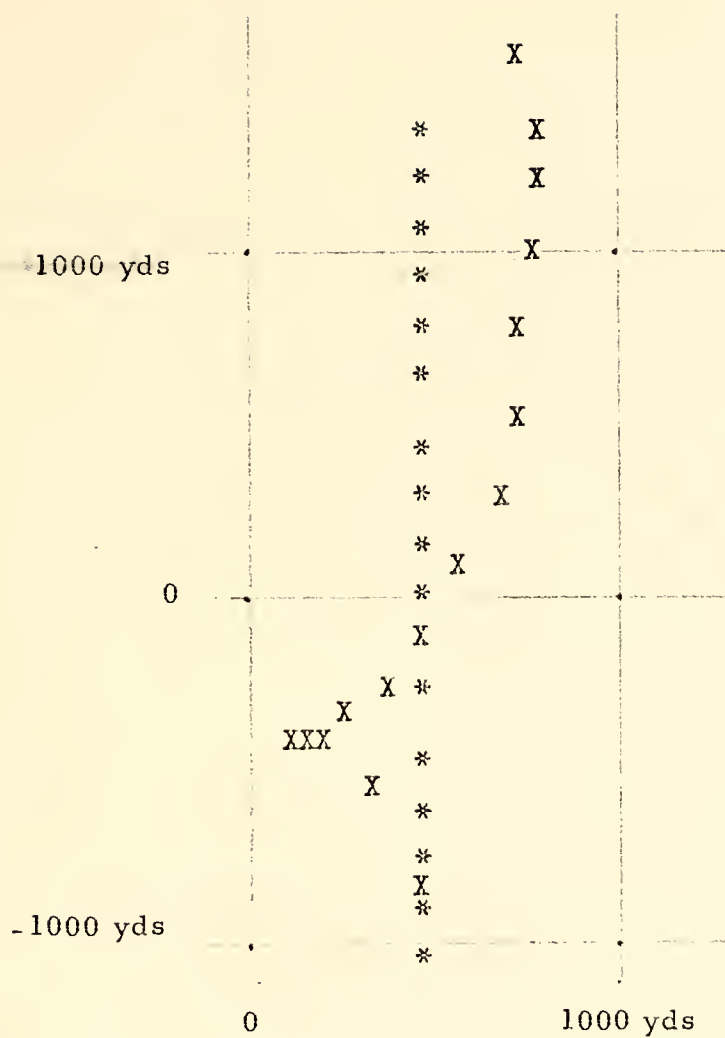
FIGURE 19. FILTER OUTPUT FOR EST. FO ⩽ F(DET),
EST. AVSK ⩾ TRUE AVSK, SA = 10°. 7th TRUE
POINT SUPPRESSED BY 8th FILTER OUTPUT
POINT.
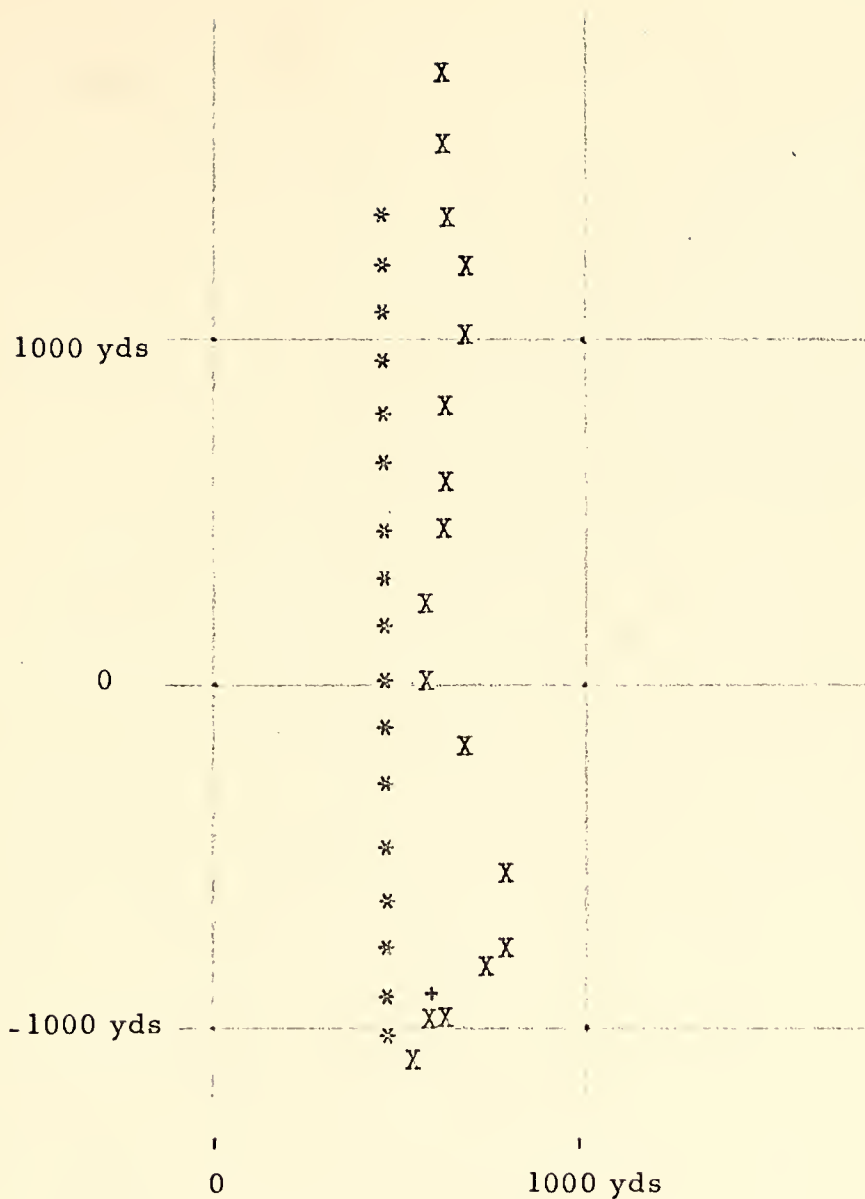
FIGURE 20.   FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
THAN F(D E T), EST. AVSK < TRUE AVSK, AND
SA = 5°.
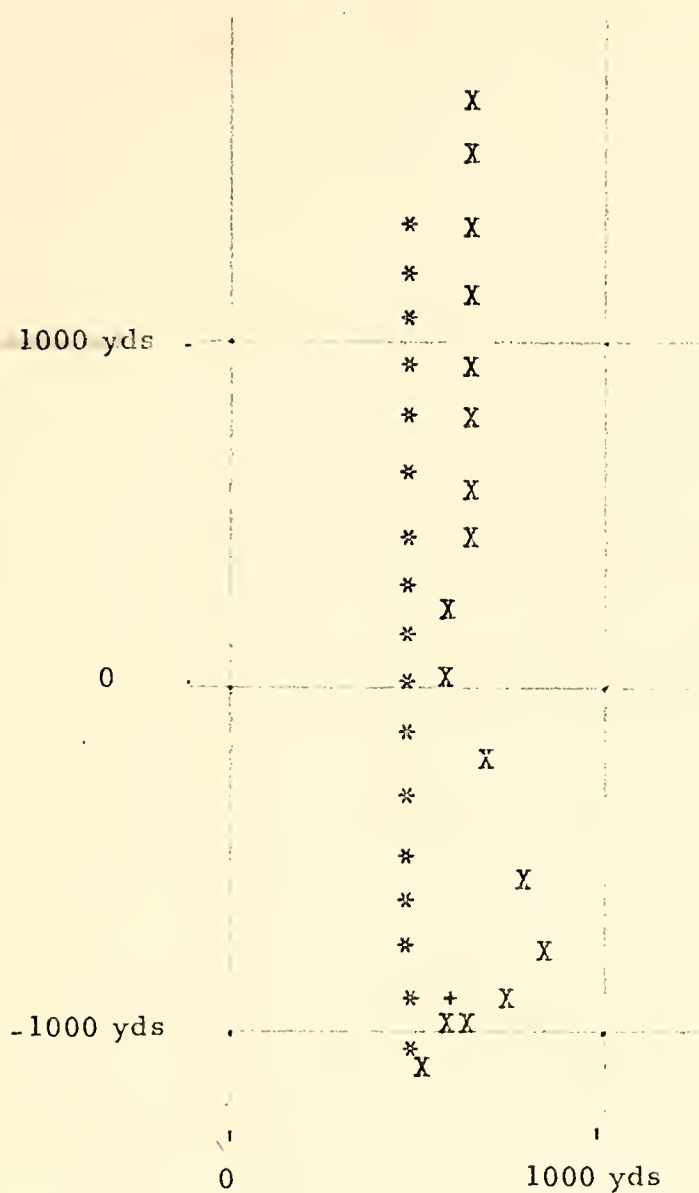
FIGURE 21. FILTER OUTPUT FOR EST. FO HIGHER OR LOWER
THAN F(DET), EST. AVSK ≈ TRUE AVSK, AND
SA = 5°.
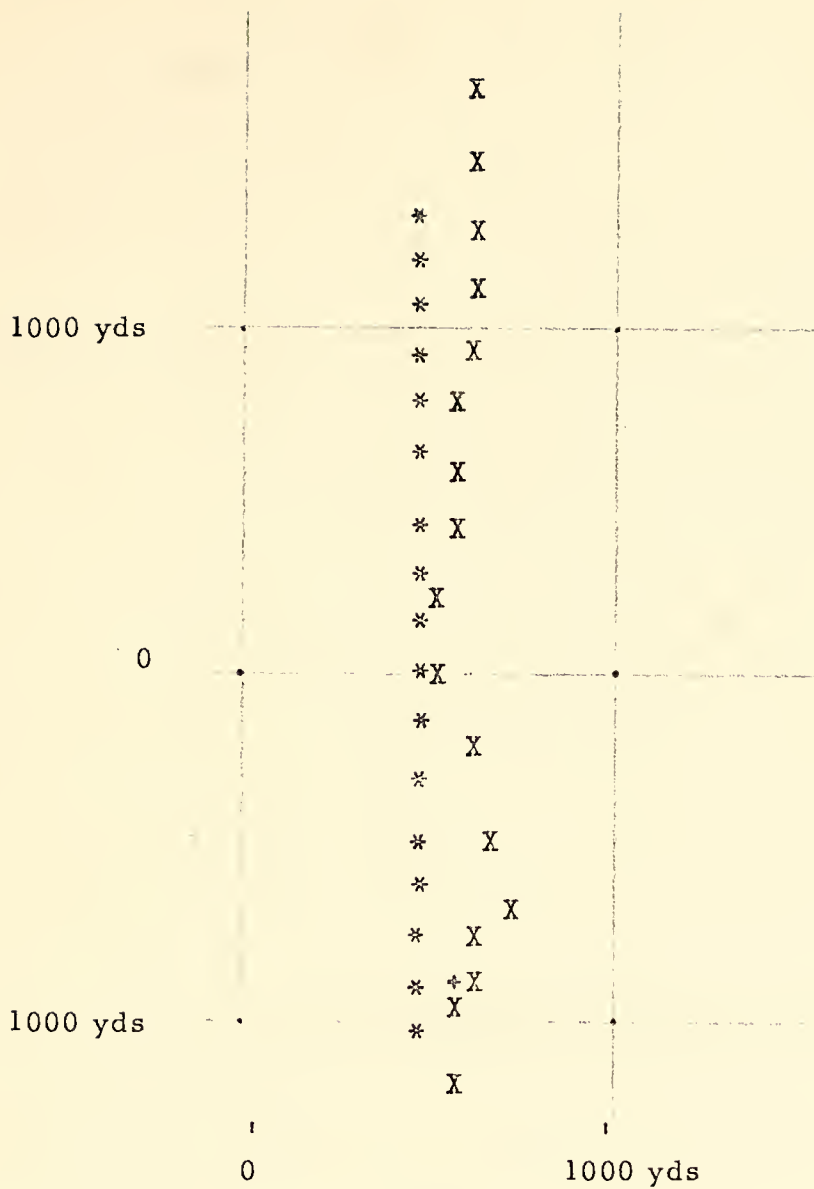
FIGURE 22. FILTER OUTPUT FOR EST. FO < F(DET), EST.
AVSK > TRUE AVSK, SA = 5°.
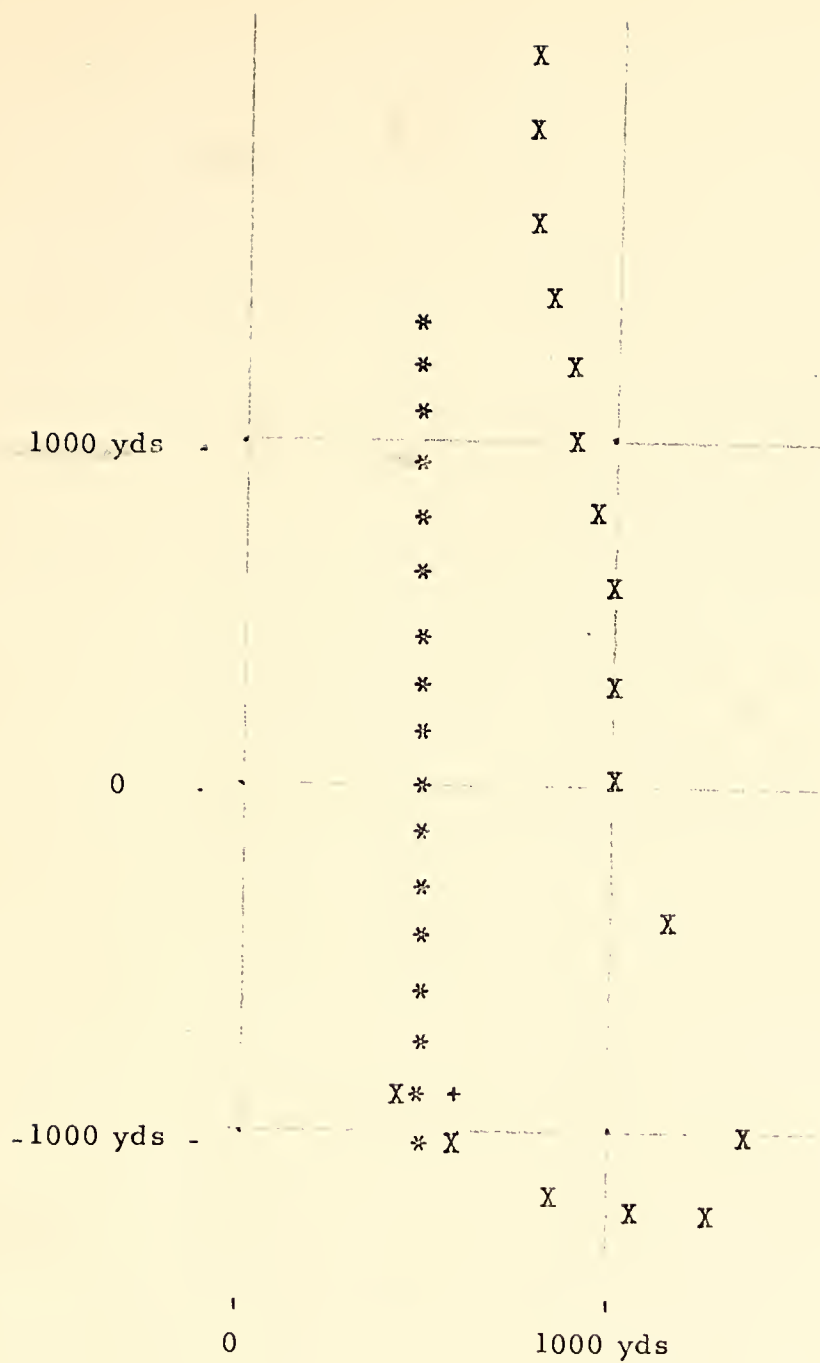
FIGURE 23.   FILTER OUTPUT FOR EST. FO > F(DET), EST.
AVSK > TRUE AVSK, SA = 5°.
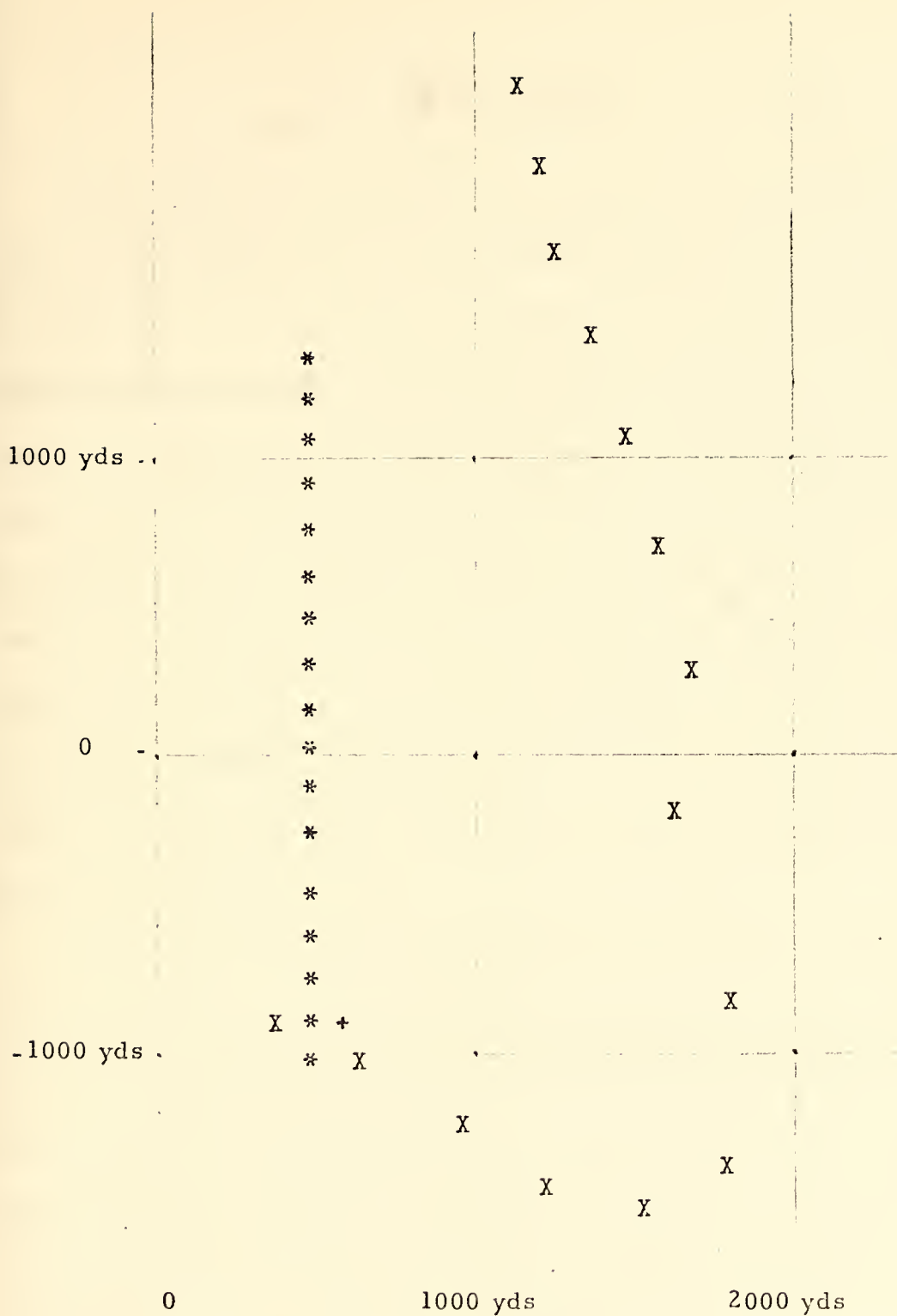
FIGURE 24. FILTER OUTPUT FOR EST. FO> F(DET), EST.
AVSK =2·TRUE AVSK, SA = 5°.

V. CONCLUSIONS

The automatic frequency tracker developed in this report has been shown to be adequate for tracking a doppler-shifting frequency in a favorable signal-to-noise ratio environment. The width of the tracking window would have to be increased for a higher speed target unless the transforms were computed at closer time intervals. A loss of signal would result in the last center bin frequency being retained as the signal being tracked unless a spurious signal with more power than the chosen minimum appeared in the window. Therefore, under marginal signal-to-noise ratio conditions, an operator would be required to monitor the frequency tracker output to insure that after a "lost track" condition occurred, any "regain track" operation was indeed occurring on the previous signal being tracked.

The procedure of using Equation (3) to extend the frequency resolution of the output above that of the FFT processing is dependent upon having a reasonable approximation of the ambient noise level. Computing a new estimate in each transform results in higher power levels than the true ambient noise level being used when the target is near CPA. Since the ratio of two numbers, A/B, is not equal to the ratio $(A-K)/(B-K)$ where K is a constant, the subtraction of the corrupted estimate of ambient noise level causes an error in the value of the resolved frequency. However, in comparing the amplitudes of the signal and

noise estimates around CPA (from Tables I, II, and III), the signal is 150 to 200 times as large as the corrupted ambient noise estimate. The resultant error on the resolved frequency is on the order of magnitude of 10^{-4}Hz and was considered negligible. As the range at CPA increases, the signal power level decreases and its corrupting influence on the ambient noise level approximation is decreased. Thus as long as the increased average power level in the window is caused by the target being tracked, no appreciable error occurs and the resolution of the overall system has been extended beyond the resolution of the FFT processing.

With real frequency inputs and reasonable initial estimates of the rest frequency and target speed, the Mitschang Filter provided target tracks in excellent agreement with the known emitter locations and probable emitter locations. Thus a true single sensor fix appears possible using existing hardware and techniques. Further testing is needed where exact target locations are known and real measured bearings are available corresponding to the real frequency measurements.

COMPUTER OUTPUT

SOUND SPEED COMPUTATION

TEMPERATURE= 48.0 DEG F   SALINITY= 35.0 PPT   DEPTH= 60.0 FEET
SOUND PROPAGATION SPEED =   1625.53 YARDS PER SECOND

INPUTS FOR FREQUENCY TRACKER SET:
LOWER FREQUENCY LIMIT OF THE SEARCH WINDOW =   220.0
SEARCH WINDOW BANDWIDTH = 20

TRANSFORMS TAKEN ONE MINUTE APART.   TIME IS IN SECONDS.

FILE 10.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20480   0.243063E 00 -0.301820E 00 -0.190762E-02 0.327662E-01

FILE 10.0 - FOURIER TRANSFORM

FILE 10.0 IN FFT.   10240 TERMS
     FACTORS: 4   2   2   5   2   4   4   0   0   0   0   0

FILE 10.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006 FOR THIS TRANSFORM.

TBIN(1)= 70 COMPUTED BY MAIN PROGRAM.

FILE 10.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:
        FTRK(1)= 223.437

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.45 TIME(1)= 10.0

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000069 0.00000206 0.0

RUN COMPLETED FOR THIS FILE NUMBER.

```
FILE  40.0 STATISTICS:        MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.255112E 00  -0.245352E 00  -0.190913E-02  0.285688E-01

FILE  40.0 - FOURIER TRANSFORM

FILE  40.0 IN FFT.     10240 TERMS
          FACTORS:
          4      2      2      5      2      4      0      0      0      0      0

FILE  40.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 2)=  71 COMPUTED BY MAIN PROGRAM.

FILE  40.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50   TIME( 2)=   70.0
                      FTRK( 2)= 223.481

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.00000094  0.00000112  0.00000011

          ----TRACKING WINDOW CHECK----

MANUEVERING TARGET OR NOISE: DOPPLER SHIFT UP      1 BINS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

```
FILE 70.0 STATISTICS:        MAX VALUE         MIN VALUE         MEAN VALUE         STD DEV
BASED ON SAMPLE SIZE OF 20480  0.3494400E 00   -0.3459968E 00   -0.1936338E-02   0.3829100E-01

FILE  70.0 - FOURIER TRANSFORM

FILE  70.0 IN FFT.     10240 TERMS
          FACTORS:
           4   4   2   2   5   2   4   4   0   0   0   0   0   0

FILE  70.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 3)=  71 COMPUTED BY MAIN PROGRAM.

FILE 70.0 LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.50  TIME( 3)=  130.0
                    FTRK( 3)= 223.495

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.00000015  0.00000061  0.00000007

          ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.
```

57

```
FILE 100.0 STATISTICS:          MAX VALUE      MIN VALUE       MEAN VALUE        STD DEV
BASED ON SAMPLE SIZE OF 20480   0.281263E 00  -0.261961E 00   -0.192759E-02    0.349617E-01

FILE 100.0 - FOURIER TRANSFORM

FILE 100.0 IN FFT.      10240 TERMS
         FACTORS:
          4    2    2    5    2    4    0    0    0    0    0

FILE 100.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN( 4)= 285 COMPUTED BY MAIN PROGRAM.

FILE 100.0 LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ  FREQUENCY BAND IS IN BIN K BELOW:
3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.20  TIME( 4) =  190.0
                        FTRK( 4)= 234.224

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.0        0.00000077  0.00000072


-----TRACKING WINDOW CHECK-----

BIN SHIFT OF  214 BINS.  RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 4) TO   72

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.55  TIME( 4) =  190.0
                     NEW FTRK( 4)= 223.556

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.00000002  0.00000052  0.00000009

RUN COMPLETED FOR THIS FILE NUMBER.
```

FILE 130.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20480   0.194444E 00   -0.174759E 00   -0.194470E-02   0.285963E-01

FILE 130.0 - FOURIER TRANSFORM

FILE 130.0 IN FFT.   10240 TERMS
       FACTORS:
       4   4   2   2   5   2   4   4   0   0   0   0   0

FILE 130.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006 FOR THIS TRANSFORM.

TBIN(5)= 71 COMPUTED BY MAIN PROGRAM.

FILE 130.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:
3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.50 TIME(5)= 250.0
                    FTRK(5)= 223.489

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000086 0.00000254 0.00000009

             ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.

```
FILE 160.0 STATISTICS:      MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480    0.206948E 00    -0.206238E 00    -0.193671E-02    0.304564E-01

FILE 160.0 - FOURIER TRANSFORM

FILE 160.0 IN FFT.      10240 TERMS
           FACTORS:
               4    2    2    5    2    4    0    0    0    0

FILE 160.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006 FOR THIS TRANSFORM.

TBIN( 6)= 70 COMPUTED BY MAIN PROGRAM.

FILE 160.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.45  TIME( 6)= 310.0
                      FTRK( 6)= 223.473

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:     0.00000006  0.00000218  0.00000201

       -----TRACKING WINDOW CHECK-----

RUN COMPLETED FOR THIS FILE NUMBER.
```

60

FILE 190.0 STATISTICS:
BASED ON SAMPLE SIZE OF 20480

MAX VALUE	MIN VALUE	MEAN VALUE	STD DEV
0.233394E 00	-0.232250E 00	-0.195899E-02	0.295174E-01

FILE 190.0 - FOURIER TRANSFORM

FILE 190.0 IN FFT.   10240 TERMS
    FACTORS:
    4   4   2   2   5   2   4   0   0   0   0

FILE 190.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000009 FOR THIS TRANSFORM.

TBIN(7)= 283 COMPUTED BY MAIN PROGRAM.

FILE 190.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 234.10 TIME(7)= 370.0
                                  FTRK(7)= 234.102

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000084   0.00000826   0.00000117

----TRACKING WINDOW CHECK----

BIN SHIFT OF 213 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(7) TO   69

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.40 TIME(7)= 370.0
                                  NEW FTRK(7)= 223.420

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000008   0.00000490   0.00000344

RUN COMPLETED FOR THIS FILE NUMBER.

61

```
FILE  220.0 STATISTICS:          MAX VALUE      MIN VALUE       MEAN VALUE        STD DEV
BASED ON SAMPLE SIZE OF 20480    0.251516E 00   -0.260181E 00   -0.193467E-02   0.314328E-01

FILE  220.0 - FOURIER TRANSFORM

FILE  220.0 IN FFT.     10240 TERMS
          FACTORS:
          4    2    2    5    2    4    0    0    0    0    0

FILE  220.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000008  FOR THIS TRANSFORM.

TBIN( 8)= 284 COMPUTED BY MAIN PROGRAM.

FILE 220.0  LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:
3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  234.15   TIME( 8)=  430.0
                  FTRK( 8)= 234.144

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.00000291  0.00000707  0.00000158

          ----TRACKING WINDOW CHECK----

BIN SHIFT OF  215 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN( 8) TO  72

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).  IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

IPRINT= 3  LAST CENTER BIN STILL SIGNIFICANT.  FURTHER CHECKS NEEDED.

LAST CENTER BIN USED WITH NEW POWER COEFFICIENTS. MODIFIED VALUES FOLLOW.

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  223.40   TIME( 8)=  430.0
                  NEW FTRK( 8)= 223.407

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.0         0.00000064  0.00000011

RUN COMPLETED FOR THIS FILE NUMBER.
```

62

FILE 250.0 STATISTICS:
BASED ON SAMPLE SIZE OF 20480

MAX VALUE	MIN VALUE	MEAN VALUE	STD DEV
0.208288E 00	-0.182077E 00	-0.194680E-02	0.320234E-01

FILE 250.0 - FOURIER TRANSFORM

FILE 250.0 IN FFT.   10240 TERMS
          FACTORS:
          4   4   2   2   5   2   4   4   0   0   0   0

FILE 250.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000024 FOR THIS TRANSFORM.

TBIN(9)= 284 COMPUTED BY MAIN PROGRAM.

FILE 250.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 234.15 TIME(9)= 490.0
                                  FTRK(9)= 234.132

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00002056 0.00003291 0.00000131

-----TRACKING WINDOW CHECK-----

BIN SHIFT OF 215 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(9) TO 70

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.45 TIME(9)= 490.0
                                  NEW FTRK(9)= 223.434

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000435 0.00000743 0.00000049

RUN COMPLETED FOR THIS FILE NUMBER.

63

```
FILE 280.0 STATISTICS:        MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480  0.220928E 00  -0.223862E 00  -0.198426E-02  0.307096E-01

FILE 280.0 - FOURIER TRANSFORM

FILE 280.0 IN FFT.   10240 TERMS
        FACTORS:
            4   2   2   5   2   4   4   0   0   0   0   0

FILE 280.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000041  FOR THIS TRANSFORM.

TBIN(10)= 284 COMPUTED BY MAIN PROGRAM.

FILE 280.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:
3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 234.15  TIME(10)= 550.0
                   FTRK(10)= 234.130

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00003518  0.00004815  0.00000075

    ----TRACKING WINDOW CHECK----

BIN SHIFT OF  214 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(10) TO  71

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.50  TIME(10)= 550.0
                   NEW FTRK(10)= 223.488

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000837  0.00002131  0.00000122

RUN COMPLETED FOR THIS FILE NUMBER.
```

FILE 310.0 STATISTICS:
BASED ON SAMPLE SIZE OF 20480   MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
                                 0.267322E 00 -0.241567E 00 -0.209375E-02 0.424228E-01

FILE 310.0 - FOURIER TRANSFORM

FILE 310.0 IN FFT.   10240 TERMS
        FACTORS:
        4   2   2   5   2   4   4   0   0   0   0   0

FILE 310.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000068 FOR THIS TRANSFORM.

TBIN(11)= 69 COMPUTED BY MAIN PROGRAM.

FILE 310.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.40 TIME(11)= 610.0
                                  FTRK(11)= 223.396

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00002000 0.00010429 0.00000939

        ----TRACKING WINDOW CHECK----

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1). IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

RUN COMPLETED FOR THIS FILE NUMBER.

65

```
FILE 340.0 STATISTICS:           MAX VALUE      MIN VALUE      MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.221991E 00  -0.229415E 00  -0.2077766E-02  0.363091E-01

FILE 340.0 - FOURIER TRANSFORM

FILE 340.0 IN FFT.   10240 TERMS
     FACTORS:
     4   4   2   2   5   2   4   0   0   0   0   0   0

FILE 340.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000050 FOR THIS TRANSFORM.

TBIN(12)= 276 COMPUTED BY MAIN PROGRAM.

FILE 340.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 233.75  TIME(12)= 670.0
                    FTRK(12)= 233.756

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000367  0.00006029  0.00001350

------TRACKING WINDOW CHECK------

BIN SHIFT OF 207 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(12) TO  62

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1). IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.05  TIME(12)= 670.0
                    NEW FTRK(12)= 223.063

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000212  0.00004795  0.00002132

RUN COMPLETED FOR THIS FILE NUMBER.
```

FILE 370.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20480   0.2175568E 00 -0.2541127E 00 -0.1983310E-02 0.3699957E-01

FILE 370.0 - FOURIER TRANSFORM

FILE 370.0 IN FFT.   10240 TERMS
        FACTORS:
        4   2   2   5   2   4   4   0   0   0   0   0

FILE 370.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000026 FOR THIS TRANSFORM.

TBIN(13)= 60 COMPUTED BY MAIN PROGRAM.

FILE 370.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 222.95   TIME(13)= 730.0
                     FTRK(13)= 222.960

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000546 0.00002554 0.00001492

-----TRACKING WINDOW CHECK-----

**CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1). IF SIGNIFICANT, IPRINT VALUE FOLLOWS.

RUN COMPLETED FOR THIS FILE NUMBER.

67

```
FILE 400.0 STATISTICS:      MAX VALUE       MIN VALUE       MEAN VALUE      STD DEV
BASED ON SAMPLE SIZE OF 20480   0.243037E 00   -0.292045E 00   -0.201376E-02   0.403838E-01

FILE 400.0 - FOURIER TRANSFORM

FILE 400.0 IN FFT.     10240 TERMS
          FACTORS:
          4    4    2    2    5    2    4    4    0    0    0    0    0

FILE 400.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000016 FOR THIS TRANSFORM.

TBIN(14)= 61 COMPUTED BY MAIN PROGRAM.

FILE 400.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 223.00   TIME(14)= 790.0
                         FTRK(14)= 222.995

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:   0.00000587  0.00002119  0.00000288

----TRACKING WINDOW CHECK----

MANUEVERING TARGET OR NOISE: DOPPLER SHIFT UP     1 BINS.

RUN COMPLETED FOR THIS FILE NUMBER.
```

FILE 430.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20480   0.1854438E 00   -0.2026603E 00   -0.197654E-02   0.2970888E-01

FILE 430.0 - FOURIER TRANSFORM

FILE 430.0 IN FFT.   10240 TERMS
        FACTORS:
        4   2   2   5   2   4   4   0   0   0   0   0   0   0

FILE 430.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000014 FOR THIS TRANSFORM.

TBIN(15)= 272 COMPUTED BY MAIN PROGRAM.

FILE 430.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 233.55 TIME(15)= 850.0
                                 FTRK(15)= 233.563

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000307 0.00001079 0.00000878

-----TRACKING WINDOW CHECK-----

BIN SHIFT OF 211 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(15) TO   60

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 222.95 TIME(15)= 850.0
                                 NEW FTRK(15)= 222.938

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000252 0.00000322 0.00000088

RUN COMPLETED FOR THIS FILE NUMBER.

69

```
FILE 460.0 STATISTICS:        MAX VALUE      MIN VALUE      MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480  0.233344E 00  -0.235275E 00  -0.198056E-02  0.314997E-01

FILE 460.0 - FOURIER TRANSFORM

FILE 460.0 IN FFT.    10240 TERMS
           FACTORS:
           4    2    2    5    2    4    0    0    0    0    0    0

FILE 460.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000010 FOR THIS TRANSFORM.

TBIN(16)= 272 COMPUTED BY MAIN PROGRAM.

FILE 460.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:
3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55   TIME(16)=  910.0
                          FTRK(16)= 233.558

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000075  0.00001018  0.00000303


-----TRACKING WINDOW CHECK-----

BIN SHIFT OF  212 BINS.  RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(16) TO  59

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90   TIME(16)=  910.0
                          NEW FTRK(16)= 222.882

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:    0.00000221  0.00000245  0.00000037

RUN COMPLETED FOR THIS FILE NUMBER.
```

70

FILE 490.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20480   0.404760E 00   -0.459381E 00   -0.201675E-02   0.375543E-01

FILE 490.0 - FOURIER TRANSFORM

FILE 490.0 IN FFT.   10240 TERMS
         FACTORS:
         4   4   2   2   5   2   4   4   0   0   0   0

FILE 490.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000004 FOR THIS TRANSFORM.

TBIN(17)= 59 COMPUTED BY MAIN PROGRAM.

FILE 490.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 222.90   TIME(17)= 970.0
                                  FTRK(17)= 222.898

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000002 0.00000060 0.0

         ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.

71

```
FILE  520.0 STATISTICS:       MAX VALUE      MIN VALUE       MEAN VALUE        STD DEV
BASED ON SAMPLE SIZE OF 20430  0.364448E 00  -0.261167E 00  -0.197170E-02   0.368306E-01

FILE  520.0 - FOURIER TRANSFORM

FILE  520.0 IN FFT:      10240 TERMS
        FACTORS:
        4     4     2     2     5     2     4     4     0     0     0     0     0

FILE  520.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000006  FOR THIS TRANSFORM.

TBIN(18)= 272 COMPUTED BY MAIN PROGRAM.

FILE  520.0 LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55   TIME(18)= 1030.0
                                  FTRK(18)= 233.545

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:      0.00000073   0.00000356   0.00000026


              ----TRACKING WINDOW CHECK----

BIN SHIFT OF  213 BINS. RECHECK TRACKED FREQ.

NEW CENTER BIN : RESET TBIN(18) TO    59

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  222.90   TIME(18)= 1030.0
                                  NEW FTRK(18)= 222.886

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:      0.00000059   0.00000112   0.00000009

RUN COMPLETED FOR THIS FILE NUMBER.
```

72

```
FILE 550.0 STATISTICS:      MAX VALUE        MIN VALUE       MEAN VALUE       STD DEV
BASED ON SAMPLE SIZE OF 20480    0.2103566E 00  -0.2257599E 00  -0.1954106E-02  0.3304900E-01

FILE  550.0 - FOURIER TRANSFORM

FILE  550.0 IN FFT.     10240 TERMS
      FACTORS:
         4     4     2     2     5     2     4     4     0     0     0     0     0     0

FILE  550.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005  FOR THIS TRANSFORM.

TBIN(19)= 272 COMPUTED BY MAIN PROGRAM.

FILE 550.0  LARGEST COEFFICIENT IN 220.0HZ  TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY=  233.55  TIME(19)= 1090.0
                         FTRK(19)= 233.530

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE:      0.00000083  0.00000130  0.0

        ----TRACKING WINDOW CHECK----

BIN SHIFT OF  213 BINS. RECHECK TRACKED FREQ.

SIGNAL FOUND IN TRACKING WINDOW IS BELOW MINIMUM VALUE.  CONTACT LOST.

RUN COMPLETED FOR THIS FILE NUMBER.
```

FILE 580.0 STATISTICS: MAX VALUE   MIN VALUE   MEAN VALUE   STD DEV
BASED ON SAMPLE SIZE OF 20460   0.239689E 00   -0.254579E 00   -0.197033E-02   0.343977E-01

FILE 580.0 - FOURIER TRANSFORM

FILE 580.0 IN FFT.   10240 TERMS
       FACTORS:
        4   4   2   2   5   2   4   4   0   0   0   0   0   0

FILE 580.0 - POWER SPECTRUM

THRESHOLD VALUE COMPUTED =0.00000005 FOR THIS TRANSFORM.

TBIN(20)= 59 COMPUTED BY MAIN PROGRAM.

FILE 580.0 LARGEST COEFFICIENT IN 220.0HZ TO 240.0HZ FREQUENCY BAND IS IN BIN K BELOW:

3 BIN RESOLUTION TRACKING VALUES: CENTER BIN FREQUENCY= 222.90 TIME(20)= 1150.0
                                  FTRK(20)= 222.901

POWER COEFFICIENTS IN BINS (K-1)/K/(K+1) ARE: 0.00000019 0.00000115 0.00000024

        ----TRACKING WINDOW CHECK----

RUN COMPLETED FOR THIS FILE NUMBER.

END OF PROGRAM.

```fortran
// EXEC FORTCLGP,REGION.GO=225K
//FORT.SYSIN DD *
      INTEGER SAMPR,SRBW,TBIN(60),BNSHF,MAXSF
      REAL YMAG(60),YA(400),TIME(60),FTRK(60)
      DIMENSION IY(20480)
      PI=3.14159
C
      WRITE(6,1)
    1 FORMAT('1',///////,47X,'COMPUTER OUTPUT',////)
C
C     COMPUTATION OF SOUND PROPAGATION SPEED.
C     TEMPERATURE IN DEG FAHRENHEIT
C     SALINITY IN PARTS PER THOUSAND
C     DEPTH IN FEET
C     VP=SPEED OF PROPAGATION IN YARDS PER SECOND
C     SET DESIRED VALUES FOR PROBLEM VARIABLES.
C
      TEMP=48.0
      SAL=35.0
      DEPTH=1470.0
      VP=1.497*(10**3)-1.97*TEMP-0.018*(TEMP)**2+1.42*(SAL-35.0)+0.0057*DEPTH
      WRITE(6,10)TEMP,SAL,DEPTH,VP
   10 FORMAT('0',17X,'TEMPERATURE=',F5.1,' DEG F',4X,'SALINITY=',
     1F7.1,/,17X,'DEPTH=',F7.1,' FEET',/,17X,
     2'SOUND PROPAGATION SPEED = ',F10.2,' YARDS PER SECOND')
C
C     SAMPR=SAMPLE RATE IN SAMPLES PER SECOND
      SAMPR=512
C     NREC=NUMBER OF RECORDS PER TRANSFORM
      NREC=10
C     NOTE: THERE ARE TWO SECONDS OF DATA PER RECORD.
C     L=NUMBER OF BINS REQUIRED PER TRANSFORM.
      L=2*NREC*SAMPR
C     RESOL=FREQUENCY RESOLUTION OF THE FFT PROCESSING.
      RESOL=1./(2*NREC)
C     SRBW=SEARCH WINDOW BANDWIDTH.
      SRBW=20
      MAXSF=20*2
C
C     FL,SRBW
C     INPUTS FOR FREQUENCY TRACKER SET.
   11 FORMAT('0',17X,'FREQUENCY TRACKER SET.',/,17X,
     1'SEARCH WINDOW =',F7.1,'TRANSFORMS TAKEN ',/,17X,
     2'SECONDS=',I13,/,17X,
C     LOWER FREQUENCY LIMIT OF THE SEARCH WINDOW=
C     NOTE: MI=INDEX NUMBER OF THE LAST
C     ON-FILE RECORD READ.
```

```
C     FILE=0.0
C     NSTRT=FIRST RECORD NUMBER TO BE ANALYZED.
      NSTRT=1
CC    NTFM=NUMBER OF TRANSFORMS TO BE COMPUTED.
      NTFM=20
C
CCC   INITIALIZE MATRICIES TO ZERO.
      DO 420 JJ=1,NTFM
C
CC    DO 20 I=1,L
      Y(I)=0.0
      IY(I)=0
   20 CONTINUE
C
      DO 30 I=1,N
      YA(I)=0.0
      YL(I)=0.0
   30 CONTINUE
C
C     N1=NSTRT-1
      IF (N1.LT.1) GO TO 50
C
CCCC  DUMMY READ TO SKIP OVER RECORDS THAT ARE NOT
      TO BE ANALYZED.
      DO 40 J=1,N1
      FILE=INT(FILE)+1.
   40 READ (2,END=50) (IY(I),I=1,2048,2)
C
   50 CONTINUE
C
CCCC  DATA TO BE ANALYZED LOADED HERE IN STEPS OF TWO.
      SINCE DATA POINT VALUES ARE REAL, ZERO VALUES
      ARE LEFT IN THE IMAJINARY (EVEN) BINS.
      JB=1
C
      DO 60 J=1,NREC
      JE=JB+2047
      READ (2,END=60) (IY(MM),MM=JB,JE,2)
      FILE=INT(FILE)+1.
      JB=JE+1
   60 CONTINUE
CCC   IY MATRIX CONTAINS ACOUSTIC DATA IN BINARY INTEGER
```

```
C     FORMAT. CONVERT TO BASE TEN FLOATING POINT
C        AND LOAD INTO THE Y MATRIX.
C
C     APPLY HANNING WINDOW FUNCTION TO REDUCE SIDE-
C        LOBEING ASSOCIATED WITH RECTANGULAR TIME WINDOWS.
C
      DO 70 J=1,L,2
      RJ=J
      Y(J)=(IY(J)/2.0**23)*SIN(2.*PI*(RJ-1)/40956.)
70    CONTINUE
C
C     CALL STATS (FILE,Y,L,YMAX,YMIN,YMEAN,YSTDEV)
C     CALL POWER (FILE,Y,L)
C
C     RETURN VALUES OF THE Y MATRIX ARE THE SPECTRUM
C        POWER COEFFICIENTS.
C     SE=LOWER FREQ LIMIT OF THE SEARCH WINDOW.
C     ISB=INTEGER NUMBER OF THE STARTING BIN OF THE
C        SEARCH WINDOW.
C
      FL=220.*FLOAT(SRBW)
      ISB=(INT(FL*2*NREC))+1
C     LOAD THE YA MATRIX WITH THE COEFFICIENTS
C        IN THE SEARCH WINDOW POWER
C     POWER IN THE APPROXIMATING WINDOW WITH THE SEARCH
C        WINDOW.  THE MAXIMUM VALUE OF YA INDEX.
C     USED TO DESIRED THRESHOLD VALUE OF POWER COMPUTE THE AVG
C        NOISE.  THE AMBIENT NOISE-USED IS DESIRED NOISE LEVEL.
C     LEVEL APPROXIMATES THE AMBIENT NOISE LEVEL NOISE
C        SIGNAL.  AND PCT-NOISE SET-USED IN BINS IN THE
C     APPROXIMATES THE SIGNAL TO NOISE.  HIGH S/N RATIOS
C        SMALL SEARCH WINDOWS AND/OR HIGH SUCH THAT THRES
C     SMALL SEARCH WINDOWS SHOULD BE LESS THAN 1.0
C
      PCT=.0
      YNOIS=0.
80    N=1.+FLOAT((ISB-2)+I)/20.
      Y(I)=Y((ISB-1)+I)+YA(I)
      YA(I)=YNOIS+YA(I)/N
      CONTINUE
C
      THRES=PCT*YNOIS
C
      DO 90 J=1,N
      YA(J)=YA(J)-THRES
      IF (YA(J).LT.0) YA(J)=0.0
```

```
C     90 CONTINUE
C        COMPUTED TIME OF DETECTED FTRK SET TO CENTER TIME OF
C        DATA USED IN COMPUTING THE TRANSFORM.
         TIME(JJ)=2.*FILE-FLOAT(NREC)
C
C        PRINT OUT THE WINDOW POWER COEFFICIENTS.
  100    WRITE(6,100)
    1    FORMAT('0YA MATRIX VALUES--PWR SPECTRUM COEFFICIENTS ',
C
  110    WRITE(6,110)
         FORMAT('0TCP LINE FREQS AS LABELED. READ L TO R, .05HZ/
C
  120    WRITE(6,120)
  130    FORMAT('0',FREQ',9(3X,'FREQ'))
  140    FORMAT('0',(5X,30(YL(I),I=1,10))
  150    FORMAT('0',(10(2X,F8.2,2X)))
         FORMAT('0',(6,140)(YA(I),I=1,N))
         FORMAT('0',(6,150)F10.8,
  12X,      THRESHOLD VALUE COMPUTED =',F10.8,
C        FOR THIS TRANSFORM.')
C
C        FIND THE BIN WITH THE MAXIMUM POWER COEFFICIENT.
         ISTOP=N-1
         YTRK=YA(1)
         K=1
         DO 160 I=1,ISTOP
         IF(YA(I+1).LT.YTRK) GO TO 160
         YTRK=YA(I+1)
         K=I+1
  160    CONTINUE
C
C        IF MAX FOUND=ZERO, GO TO NEXT RECORD. THIS WOULD
C        OCCUR ONLY FOR VALUES OF PC- GREATER THAN ONE IN A
C        LOW SIGNAL TO NOISE RATIO ENVIRONMENT.
         IF (YTRK.EQ.0.) GO TO 400
C
C        K CONTAINS THE NUMBER OF THE BIN CONTAINING YTRK.
         KL=K-2
         KU=K+2
C
C        SET CENTER BIN OF TRACKING WINDOW =TBIN(JJ) AND
C        TRACKED FREQ = THE VALUE OF THE FREQ BIN CONTAINING
         YTRK=K
         TBIN(JJ)=K
```

1300
1310
1320
1330
1340
1350
1360
1370
1380
1390
1400
1410
1420
1430
1440
1450
1460
1470
1480
1490

1510
1520
1530
1540
1550
1560
1570
1580
1590
1600
1610
1620
1630
1640
1650
1660
1680
1690
1700
1710
1720
1730
1740
1750
1760

78

```
      FTRK(JJ)=YL(K)                                                      1770
      YMAG(JJ)=YA(K)                                                      1780
      WRITE(6,170) JJ,TBIN(JJ)                                            1790
  170 FORMAT('0',17X,'J=',I2,')=',I4,' COMPUTED BY MAIN PROGRAM.')        1810
      WRITE(6,130)FILE,FL,FU                                              1840
  130 FORMAT('0',17X,FILE,F6.1,2X,'LARGEST COEFFICIENT IN',F6.1,2X,'HZ',  1850
     1'0',F6.1,'HZ FREQUENCY BAND IS IN BIN K BELOW:')                    1860
C                                                                         1870
C     IF MAX IS OCCURING NEAR LIMITS OF SRBW, DO NOT FILTER               1880
      IF(KL.LT.1) GO TO 200                                               1890
      IF(KU.GT.N) GO TO 200                                               1900
C                                                                         1910
      KL=K-1                                                              1920
      KU=K+1                                                              1930
      FTRK(JJ)=YL(K)+RESOL*((YA(K+1)-YA(K-1))/(YA(K-1)+YA(K+1)))          1940
      WRITE(6,191)J,TIME(JJ),J,FTRK(JJ),K,YA(J),J=KL,KU)                  1950
  191 FORMAT('0',18X,'BIN RESOLUTION TRACKING VALUES: CENTER BIN:',I2,    1960
     1'0',18X,'POWER COEFFICIENTS IN BINS (K-1),K,(K+1) ARE:',3F7.1)      1970
      WRITE(6,190)YL(K),J,FTRK(JJ),J,TIME(JJ)                             1980
  190 FORMAT('0',03 BIN RESOLUTION TRACKING VALUES: FREQ=',F8.2,          1990
     13X,'NEW FTRK(',I2,')=',F8.3,/,10X,'NEW FTRK(',I2,')=',F8.3)         2000
      GO TO 220                                                           2010
  200 CONTINUE                                                            2020
      WRITE(6,210)                                                        2030
  210 FORMAT('0',6X,'MAX OCCURING NEAR LIMITS OF SRBW, RESET FL.')        2040
      WRITE(6,190)YL(K),(YA(J),J=KL,KU),JJ,FTRK(JJ),JJ,TIME(JJ)          2050
  220 CONTINUE                                                            2060
      IF(JJ.LT.2) GO TO 400                                               2070
C                                                                         2080
C     TRACKING WINDOW SECTION OF PROGRAM STARTS HERE.                     2090
C                                                                         2100
      WRITE(6,230)                                                        2110
  230 FORMAT('0',/,30X,'----TRACKING WINDOW CHECK----')                   2130
      THMIN=3.*THRES                                                      2140
C                                                                         2150
C     MAXSF=MAX ALLOWED BINSHIFT OF THE TRACKED                           2160
C     SIGNAL FROM ITS VALUE IN THE LAST TRANSFORM.                        2170
C     BINSHF = BIN SHIFT                                                  2180
C                                                                         2190
```

79

```
      MAXSF=10
      BNSHF=TBIN(JJ)-TBIN(JJ-1)
      BNSHF=TBIN(JJ)-TBIN(JJ-1)
      IF(BNSHF.GT.0) GO TO 240
      IF(BNSHF.GT.MAXSF) GO TO 260
      BNSHF=-BNSHF
  240 IF(BNSHF.GT.MAXSF) GO TO 260
      IF(IFLAG.EQ.0) WRITE (6,250) BNSHF
  250 FORMAT(10,17X,'MANEUVERING TARGET OR NOISE: DOPPLER SHIFT UP ',
     1I4,' BINS.')
      IFLAG=1
      IF(BNSHF.GT.1) GO TO 240
      GO TO 400
  260 WRITE (6,270) BNSHF
  270 FORMAT('0',17X,'BIN SHIFT OF ',I4,' BINS. RECHECK TRACKED FREQ.')
C
C     CENTER BIN OF TRACKING WINDOW = ITS VALUE IN THE
C     LAST TRANSFORM. CHECK THE NEW POWER COEF-
C     FICIENTS FOR THE TRACKING WINDOW BINS.
C
C     FIND THE MAXIMUM POWER COEFFICIENT IN THE WINDOW.
      YMAX=YA(IR-10)
      IK=1
      DO 280 I=1,20
      IF(YA(IR-10+I).LT.YMAX) GO TO 280
      YMAX=YA(IR-10+I)
      IK=IR-10+I
  280 CONTINUE
C
C     IK CONTAINS THE NUMBER OF THE BIN CONTAINING THE
C     MAXIMUM FOUND. IF NO SIGNAL FOUND, BRANCH TO STMT
C     320. RESET CENTER BIN TO ITS VALUE IN THE LAST
C     TRANSFORM AND RETURN.
      IF(YMAX.LE.THMIN) GO TO 320
C
C     SET FTRK AND TBIN VALUES BASED ON MAXIMUM FOUND.
      FTRK(JJ)=YL(IK)
      FMAX=YL(IK)
      TBIN(JJ)=IK
```

```
      YMAG(JJ)=YA(IK)
  290 WRITE(6,290)JJ,TBIN(JJ)
      FORMAT(1H0,17X,'NEW CENTER BIN : RESET TBIN(',I2,') TO ',I4)
      BNSHF=TBIN(JJ)-TBIN(JJ-1)
      IF(BNSHF.LT.0) BNSHF=-BNSHF
C
      IFLAG=2
  300 IF(BNSHF.GT.1) GO TO 340
C
      IKL=IK-1
      IKU=IK+1
      FTRK(JJ)=YL(IK)+RESOL*((YA(IK+1)-YA(IK-1))/(YA(IK-1)+YA(IK)+YA(IK+
     1 1)))
      WRITE(6,310) FMAX,(YA(J),J=IKL,IKU),FTRK(JJ),JJ,TIME(JJ),JJ,
  310 FORMAT(' RESOLUTION TRACKING VALUES:  FREQ#=',F8.2,
     1 ' NEW FTRK(',I2,')=',F8.3,
     2 ' NEW FTRK(',I2,')=',I4)
C
      GO TO 400
C
  320 WRITE(6,330)
  330 FORMAT(1H0,17X,'SIGNAL FOUND IN TRACKING WINDOW IS BELOW',
     1 ' MINIMUM VALUE.  CONTACT LOST.')
      IBIN(JJ-1)=TBIN(JJ-1)
      FTRK(JJ)=0.
      GO TO 400
C
  340 IPRINT=1
  350 WRITE(6,350)
      FORMAT(1H0,17X,'CHECKING POWER IN OLD CENTER BIN, TBIN(JJ-1).',
     1 ' VALUE FOLLOWS:')
      IPRINT=IPRINT+1
      IF(IPRINT.GT.1) IPRINT=IPRINT+1
      IF(IPRINT.GT.1) GO TO 300
      IF(YA(IK).LT.300.) IPRINT=IFLAG
      WRITE(6,360) IPRINT
  360 FORMAT(1H0,17X,'LAST CENTER BIN STILL ',I2,
     1 ' SIGNIFICANT.  FURTHER CHECKS NEEDED.')
C
C     DOUBLE SIZE OF OLD SIGNAL FOR COMPARISON WITH NEW ONE
C
```

```
      A=2.*YA(IR)
C     NOTE--- INDEXING DIFFERENCES REQUIRE DIFFERENT
C     SECTIONS TO MAKE THE SAME TESTS OF SIGNIFICANCE.
      IF (IFLAG.EQ.2) GO TO 390
C     IS THE OLD SIGNAL AT LEAST HALF AS LARGE AS THE NEW.
C     IF NOT, CONSIDER NEW SIGNAL GOOD, GO TO NEXT TRANSFORM
      IF (A.LT.YA(K)) GO TO 400
C     NO BRANCH ABOVE, OLD SIGNAL NEEDS FURTHER CHECKS.
C     RESET OLD SIGNAL TO ITS ORIGINAL SIZE.
      A=A/2.
C     IS THE OLD SIGNAL LARGER THAN TPMIN
      IF (A.GT.THMIN) GO TO 370
C     IF NEW SIGNAL LARGER THAN THMIN
      IF (YA(K).LT.THMIN) GO TO 320
C     TO 400 OLD SIGNAL IS SIGNIFICANT AND WILL BE USED AS THE
C     TRACKED SIGNAL. CHANGE INDEXING TO CONFORM TO THE
  310 WRITE FORMAT.
      JJ=IR
  370 BIN(JJ)=IR
      YAG(JJ)=YL(IR)
      FMAX=YA(IR)
      WRITE (6,380)
  380 FORMAT(1H0,17X,"LAST CENTER BIN USED WITH NEW POWER ",
     * "COEFFICIENTS. MODIFIED VALUES FOLLOW.")
    1 GO TO 300
C     STEPS IN THE FOLLOWING SEQUENCE ARE THE SAME LOGIC
C     AS ABOVE BETWEEN STATEMENTS 360 AND 370.
  390 IF (A.LT.YA(IK)) GO TO 300
      IF (A/2..GT.THMIN) GO TO 370
      IF (YA(IK).LT.THMIN) GO TO 320
      GO TO 300
C     TRACKING WINDOW SECTION ENDS HERE.
  400 CONTINUE
      NSTRT=...
      NSTRT=NSTRT+...
C     VALUE CHANGED SO THE NEXT DATA READ IS
C     TAPE. BY A SUITABLE CHOSEN AMOUNT OF TIME.
      WRITE (6,410)
```

```
 410  FORMAT ('0',17X,'RUN COMPLETED FOR THIS FILE NUMBER.')        3570
C     IF JJ IS LESS THAN NTFM, RETURN.                              3580
C                                                                   3590
 420  CONTINUE                                                      3600
C                                                                   3610
      WRITE (6,430)                                                 3620
 430  FORMAT ('1PLOT OF FREQ VRS TIME TO SHOW DOPPLER SHIFT')       3630
      CALL PLOTP (TIME,FTRK,NTFM,0)                                 3640
      WRITE (6,440)                                                 3650
 440  FORMAT ('1PLOT OF POWER MAGNITUDE VRS TIME')                  3660
      CALL PLOTP (TIME,YMAG,NTFM,0)                                 3670
 450  FORMAT ('0',17X,'END OF PROGRAM.')                            3690
      STOP                                                          3700
      END
C
C
C
      SUBROUTINE STATS (FILE,Y,L,YMAX,YMIN,YMEAN,YSTDEV)             10
C                                                                   20
      REAL Y(L)                                                     30
 10   FORMAT ('1',///17X,///,'FILE=',F6.1,' STATISTICS:',10X,'MAX VALUE',6X   50
     1 'MIN VALUE',6X,'STD DEV',2X/,I5,4(2X,E13.6))                 60
     2 ' BASED ON SAMPLE SIZE OF ',I5,4(2X,E13.6))                  70
      YMAX=Y(1)                                                     80
      YMIN=Y(1)                                                     90
      YMEAN=Y(1)                                                    100
      SSQUS=Y(1)**2                                                 110
C                                                                   120
      DO 20 I=2,L                                                   130
      IF (Y(I).GT.YMAX) YMAX=Y(I)                                   140
      IF (Y(I).LT.YMIN) YMIN=Y(I)                                   150
      YMEAN=YMEAN+Y(I)                                              160
      SSQUS=SSQUS+Y(I)**2                                           170
 20   CONTINUE                                                      180
C                                                                   190
      YMEAN=YMEAN/FLOAT(L)                                          200
      YSTDEV=SQRT((SSQUS-FLOAT(L)*YMEAN*YMEAN)/FLOAT(L-1))          210
      WRITE (6,10) FILE,L,YMAX,YMIN,YMEAN,YSTDEV                    220
      RETURN                                                        230
      END
C
C
C
      SUBROUTINE POWER (FILE,Y,L)                                   10
C                                                                   20
```

83

```
C     DESCRIPTION - SUBROUTINE POWER FINDS THE FOURIER TRANSFORM OF THE DATA IN
C     ARRAY Y.  FROM THE TRANSFORM THE POWER SPECTRUM IS COMPUTED. AND
C     THE FOURIER COEFFICIENT FFT ALGORITHMS ARE COMPUTED BY SUBROUTINE FFREAL. AND
C     SUBROUTINE FFT.  ALGORITHMS WRITTEN BY R. C. SINGLETON OF THE
C     STANFORD RESEARCH INSTITUTE.
C
C     NOTE:  THIS SUBROUTINE ALTERS THE DATA PASSED TO IT.
C
      REAL XL(10),XI(10)
10    Y(L)
      FORMAT('0',17X,'FILE ',F6.1,'   - POWER SPECTRUM')
      L=L/2
      CALL FFREAL (FILE,Y,Y(2),N,+2)
      DO 20 I=1,N
      Y(I)=Y(2*I-1)**2+Y(2*I)**2
20    CONTINUE
      WRITE (6,10) FILE
      RETURN
      END
C
COMMENT:  SUBROUTINE FFREAL
C
C     PARAMETERS -
C     FILE = A REAL VARIABLE IDENTIFYING THE CURRENT DATA FILE.
C            (FOR USER IDENTIFICATION PURPOSES ONLY.)
C     A    = A REAL ARRAY CONTAINING THE DATA TO BE TRANSFORMED.
C            ON RETURN A CONTAINS THE COSINE AND SINE CO-
C            EFFICIENTS OF THE TRANSFORM FOR THE 1ST THROUGH THE
C            N/2 TH HARMONIC.
C     B    = THE SECOND ELEMENT OF ARRAY A; I.E., ARRAY A(2).
C     N    = AN INTEGER EQUAL TO 1/2 THE SIZE OF ARRAY A.
C            ON RETURN N IS SET SLIGHTLY SMALLER THAN THE VALUE
C            ORIGINALLY PASSED. (SEE SUBPROGRAM FFT.)
C     ISN  = AN INTEGER; +2 IF THE REAL TRANSFORM IS TO BE
C            PREFORMED; -2 IF THE INVERSE TRANSFORM IS DESIRED.
C
C     DESCRIPTION - SUBROUTINE FFREAL COMPUTES THE FOURIER TRANSFORM OF
C     N/2+2 REAL DATA VALUES AND RETURNS THE FOURIER COEFFICIENTS ARE AUTO-
C     MATICALLY SCALED BY THE USUAL SCALE FACTOR OF 1/(2*N)=1/N. FOURIER
C     INVERSE TRANSFORM. IF THE INVERSE FOURIER TRANSFORM IS
C            IN THIS CASE THE SCALE FACTOR IS 1/2.
```

```fortran
C     IN BOTH CASES, SUBROUTINE FFT IS CALLED TO PREFORM THE ACTUAL
C     TRANSFORM.
C
C     REFERENCE:
C     SINGLETON, R. C., "ALGORITHM FOR MIXED RADIX FFT", IEEE TRANS-
C     ACTIONS ON AUDIO AND ELECTROACOUSTICS, VOL.AU-17, NO.2,
C     PP. 93-103, JUNE 1969.
C
      SUBROUTINE FFREAL (FILE,A,B,N,ISN)
      REAL A(1),B(1)
   10 FORMAT (' ',17X,'FILE ',F6.1,' - FOURIER TRANSFORM')
      WRITE (6,10) FILE
      INC=IABS(ISN)
      SN=0.
      IF (ISN.LT.0) GO TO 40
      CALL FFT (FILE,A,B,N,ISN)
      NC=INC+2
      NK=NC/2
      SD=2.0*ATAN(1.0)/FLOAT(N)
      SD=2.0*SIN(SD)**2
      CD=SIN(SD+SD)
      A(NK-1)=A(1)
      B(NK-1)=B(1)
      SC=1./(2.*
C
   20 DO 30 J=1,NH,INC
      DK=A(J)+A(K)
      AA=A(J)-A(K)
      BB=B(J)+B(K)
      CN=CN+SN*AB
      SN=SN+CD*AB
      BB=B(J)-B(K)
      RE=I+I+I+(CN+SN)*SC
      BD=A(K)+(BB)*SC
      A(K)=(DK-CN*DK+SD*SN)
      A(J)=(DK+CN*DK-SD*SN)
      B(K)=(CD-CD*SN+SD*SN)
      SN=(SD*CD-CD*SN)+SN
      CN=CN-(SD*CN+CD*SN)**2+SN
      CN=0.5/(AA**2+SN**2)+0.5
      SN=CN
   30 ...
      IF (ISN.GT.0) RETURN
      CALL FFT (FILE,A,B,N,ISN)
      RETURN
C
```

```
40  CN=-1.0
    NH=NK/2*INC+2
    ZN=NK/2*INC+2
    SOD=2.0*ATAN(1.0)/FLOAT(N)
    COD=2.0*SIN(SD)**2
    SD=SIN(SD+SD)
    SC=0.5
    GO TO 20
    END

COMMENT: SUBROUTINE FFT
C
C  PARAMETERS
C  FILE = (REAL VARIABLE) THE CURRENT DATA FILE.
C
C  A    =  THE ARRAY CONTAINS ONLY THE REAL COMPONENTS OF
C          THE ORIGINAL DATA.
C
C  B    =  THE ARRAY CONTAINS THE IMAGINARY COMPONENTS OF
C          THE ORIGINAL DATA; I.E., THE SINE
C          COEFFICIENTS OF THE FOURIER TRANSFORM.
C
C  N    =  (INTEGER VARIABLE) EQUAL TO THE SIZE OF DATA IN
C          THE ARRAY A.
C
C  ISN  =  (INTEGER VARIABLE) A IS THE STEP SIZE OF
C          THE ARRAYS AND DETERMINES WHETHER
C          THE COMPLEX OR INVERSE TRANSFORM WILL BE PREFORMED.
C
C  DESCRIPTION
C  COMPUTES THE SINGLE-VARIATE COMPLEX FOURIER
C  TRANSFORM USING A FIXED-RADIX FAST FOURIER
C  TRANSFORM SUBPROGRAM IN PLACE.  THE SUBPROGRAM IN
C  TURN IS CALLED BY CONDITIONS AND NP(MAXP)
C  ARRAY XX IS AVAILABLE STORAGE.
C  IF NK .GE. 13,
C  SQUARE-FREE FACTOR OF N HAS TWO OR
C  MORE SQUARE-FREE PRIME FACTORS OF N.
C  THE MAXIMUM PRIME FACTOR OF
C  N IS 23.
C
```

```
C     REFERENCE:
C     SINGLETON, R. C., "ALGORITHM FOR MIXED RADIX FFT", IEEE TRANS-
C     ACTIONS ON AUDIO AND ELECTROACOUSTICS, VOL.AU-17, NO.2,
C     PP. 93-103, JUNE 1969.
C
      SUBROUTINE FFT (FILE,A,B,N,ISN)
      REAL A(1),B(1),NP(209)
      DIMENSION NFAC(13),NP(209)
      DIMENSION AT(23),CK(23),BT(23),SK(23)
      EQUIVALENCE (I,II)
C     SET NFAC TO ZERO
 10   DO 20 I=1,13
 20   NFAC(I)=0
C
C     THE FOLLOWING TWO CONSTANTS SHOULD AGREE WITH THE ARRAY DIMENSIONS.
C
      NTOT=N
      NSPAN=N
      MAXF=23
      MAXP=209
C
      IF (ISN.EQ.0) GO TO 580
      INC=ISN
      C72=0.30901699437494742
      S72=0.95105651629515357
      S120=0.86602540378443865
      RAD=0.28318530717958
      IF (ISN.GE.0) GO TO 30
      S120=-S120
      RAD=-RAD
      INC=-INC
      KSPAN=INC
      NT=INC*NTOT
      KS=INC*NSPAN
      KSPNN=KS
      JC=KS/N
      RADF=RAD*FLOAT(JC)*0.5
      JF=0
 30   I=0
C
C     DETERMINE THE FACTORS OF N
C
      K=0
      M=N
      GO TO 50
```

87

```
840   40  M=M+1
850       NFAC(M)=4
860       K=K/16
870   50  IF(K-(K/16)*16.EQ.0) GO TO 40
880       JJ=3
890       GO TO 70
900   60  M=M+1
910       NFAC(M)=J
920       K=K/JJ
930   70  IF(MOD(K,JJ).EQ.0) GO TO 60
940       J=J+2
950       JJ=J*2
960       IF(JJ.LE.K) GO TO 70
970       IF(K-1.4) GO TO 80
980       KT=M
990       NFAC(M+1)=K
1000  80  IF(K.NE.1) M=M+1
1010      IF(K-(K/4)*4.NE.0) GO TO 90
1020      M=M+1
1030      NFAC(M)=2
1040      K=K/4
1050  90  KT=M
1060      J=2
1070 100  IF(MOD(K,J).NE.0) GO TO 110
1080      M=M+1
1090      NFAC(M)=J
1100      K=K/J
1110 110  J=((J+1)/2)*2+1
1120      IF(J.LE.K) GO TO 100
1130 120  IF(KT.EQ.0) GO TO 140
1140      J=KT
1150 130  M=M+1
1160      NFAC(M)=NFAC(J)
1170      J=J-1
1180      IF(J.NE.0) GO TO 130
1190 140  DO 150 III=1,13
1200      IF(NFAC(III).GT.MAXF) GO TO 630
1210 150  CONTINUE
1220  C
1230      NPROD=NFAC(1)
1240  C
1250  C
1260      DO 170 III=2,13
1270      IF(NFAC(III).LT.1) GO TO 180
1280      IIII=III-1
1290  C
```

88

```
      DO 160 KKK=1,IIII
      IF (NFAC(III).EQ.NFAC(KKK)) GO TO 170
  160 CONTINUE
C
  170 NPROD=NPROD*NFAC(III)
      CONTINUE
C
  180 NPROD=NPROD-1
      IF (NPROD.GT.MAXP) GO TO 630
      WRITE (6,190) FILE,N,NFAC
  190 FORMAT ('0',17X,'FILE ',F6.1,' IN FFT.',4X,I5,' TERMS',/,
     1 28X,'FACTORS',/28X,13I5)
CCC
C     COMPUTE FOURIER TRANSFORM
CCC
  200 SD=RADF/FLOAT(KSPAN)
      CD=2.0*SIN(SD)**2
      SD=SIN(SD+SD)
      KK=1
      I=I+1
      IF (NFAC(I).NE.2) GO TO 250
CCC
C     TRANSFORM FOR FACTOR OF 2 (INCLUDING ROTATION FACTOR)
CCC
  210 KSPAN=KSPAN/2
      K1=KSPAN+2
      K2=KK+KSPAN
      AK=A(KK)-A(K2)
      BK=B(KK)-B(K2)
      A(KK)=A(KK)+A(K2)
      B(KK)=B(KK)+B(K2)
      KK=K2+KSPAN
      IF (KK.LE.NN) GO TO 210
      KK=KK-NN
      IF (KK.LE.JC) GO TO 210
      IF (KK.GT.KSPAN) GO TO 440
  220 C1=1.0-CD
      S1=SD
  230 K2=KK+KSPAN
      AK=A(KK)-A(K2)
      BK=B(KK)-B(K2)
      A(KK)=A(KK)+A(K2)
      B(KK)=B(KK)+B(K2)
      A(K2)=C1*AK+S1*BK
      B(K2)=C1*BK-S1*AK
      KK=K2+KSPAN
```

89

```
1800        IF(KK.LT.NT) GO TO 230
1810        K2=KK+NT
1820        C1I=-C1-K2
1830        KKK=K1-K2
1840        IF(KK.GT.K2) GO TO 230
1850        AK=CD*C1+SD*S1
1860        S1I=(SD*C1-CD*S1)+S1
1870        C1I=C1I-AK
1880        KKK=KK+JC
1890        IF(KK.LT.K2) GO TO 230
1900        KK1=K1+INC
1910        KKK=(KK1-KSPAN)/2+JC
1920        IF(KK.LE.JC+JC) GO TO 220
1930        GO TO 200
1940  C
1950  C     TRANSFORM FOR FACTOR OF 3 (OPTIONAL CODE)
1960  C
1970  240   K1=KK+KSPAN
1980        K2=K1+KSPAN
1990        AK=A(KK)
2000        BK=B(KK)
2010        AJ=A(K1)+A(K2)
2020        BJ=B(K1)+B(K2)
2030        A(KK)=AK+AJ
2040        B(KK)=BK+BJ
2050        AK=-0.5*AJ+AK
2060        BK=-0.5*BJ+BK
2070        AJ=(A(K1)-A(K2))*S120
2080        BJ=(B(K1)-B(K2))*S120
2090        A(K1)=AK-BJ
2100        B(K1)=BK+AJ
2110        A(K2)=AK+BJ
2120        B(K2)=BK-AJ
2130        KK=K2+KSPAN
2140        IF(KK.LT.NN) GO TO 240
2150        KK=KK-NN
2160        IF(KK.LE.KSPAN) GO TO 240
2170        GO TO 400
2180  C
2190  C     TRANSFORM FOR FACTOR OF 4
2200  C
2210  250   IF(NFAC(I).NE.4) GO TO 340
2220        KSPNN=KSPAN
2230        KSPAN=KSPAN/4
2240  260   C1=1.0
2250        S1=0
2260  270   K1=KK+KSPAN
2270        K2=K1+KSPAN
```

```
2760       B(K2)=BJP
2770       A(K3)=AKM
2780       B(K3)=BKM
2790       KK=K3+KSPAN
2800       IF (KK.LE.NT) GO TO 270
2810       GO TO 290
2820
2830 C     TRANSFORM FOR FACTOR OF 5 (OPTIONAL CODE)
2840 C
2850   320 C2=C72**2-S72**2
2860       S2=2.0*C72*S72
2870   330 K1=KK+KSPAN
2880       K2=K1+KSPAN
2890       K3=K2+KSPAN
2900       K4=K3+KSPAN
2910       AKP=A(K1)+A(K4)
2920       AKM=A(K1)-A(K4)
2930       BKP=B(K1)+B(K4)
2940       BKM=B(K1)-B(K4)
2950       AJP=A(K2)+A(K3)
2960       AJM=A(K2)-A(K3)
2970       BJP=B(K2)+B(K3)
2980       BJM=B(K2)-B(K3)
2990       AA=A(KK)
3000       BB=B(KK)
3010       A(KK)=AA+AKP+AJP
3020       B(KK)=BB+BKP+BJP
3030       AK=AKP*C72+AJP*C2+AA
3040       BK=BKP*C72+BJP*C2+BB
3050       AJ=AKM*S72+AJM*S2
3060       BJ=BKM*S72+BJM*S2
3070       A(K1)=AK-BJ
3080       B(K1)=BK+AJ
3090       A(K4)=AK+BJ
3100       B(K4)=BK-AJ
3110       AK=AKP*C2+AJP*C72+AA
3120       BK=BKP*C2+BJP*C72+BB
3130       AJ=AKM*S2-AJM*S72
3140       BJ=BKM*S2-BJM*S72
3150       A(K2)=AK-BJ
3160       B(K2)=BK+AJ
3170       A(K3)=AK+BJ
3180       B(K3)=BK-AJ
3190       KK=K4+KSPAN
3200       IF (KK.LT.NN) GO TO 330
3210       KK=KK-NN
3220       IF (KK.LE.KSPAN) GO TO 330
3230       GO TO 490
```

```
      C
      C    TRANSFORM FOR ODD FACTORS
3240  340 K=NFAC(I)
3250      KNN=KSPAN/K
3260      KSPAN=KSPAN/K
3270      IF(K.EQ.3) GO TO 240
3280      IF(K.EQ.5) GO TO 320
3290      IF(K.EQ.JF) GO TO 360
3300      JF=K
3310      S1=RAD/FLOAT(K)
3320      C1=COS(S1)
3330      S1=SIN(S1)
3340      IF(JF.GT.MAXF) GO TO 540
3350      CK(JF)=1.0
3360      SK(JF)=0.0
3370      J=1
3380  350 CK(J)=CK(K)*C1+SK(K)*S1
3390      SK(J)=CK(K)*S1-SK(K)*C1
3400      K=K-1
3410      CK(K)=CK(J)
3420      SK(K)=-SK(J)
3430      J=J+1
3440      IF(J.LT.K) GO TO 350
3450  360 K1=KK+KSPNN
3460      K2=KK+KSPNN
3470      AA=A(KK)
3480      BB=B(KK)
3490      AK=AA
3500      BK=BB
3510      J=1
3520  370 K1=K1+KSPAN
3530      K2=K2-KSPAN
3540      J=J+1
3550      AT(J)=A(K1)+A(K2)
3560      AK=AT(J)+AK
3570      BT(J)=B(K1)+B(K2)
3580      BK=BT(J)+BK
3590      J=J+1
3600      AT(J)=A(K1)-A(K2)
3610      BT(J)=B(K1)-B(K2)
3620      K1=K1+KSPAN
3630      IF(K1.LT.K2) GO TO 370
3640      A(KK)=AK
3650      B(KK)=BK
3660      K1=KK
3670      K2=KK+KSPNN
3680      J=1
```

```fortran
  360 K1=K1+KSPAN
      K2=K2-KSPAN
      JJ=J
      AK=AA
      BK=BB
      AJ=0.0
      BJ=0.0
  390 K=K+1
      AK=AT(K)*CK(JJ)+AK
      BK=BT(K)*CK(JJ)+BK
      AJ=AT(K)*SK(JJ)+AJ
      BJ=BT(K)*SK(JJ)+BJ
      JJ=JJ+J
      IF(JJ.GT.JF) JJ=JJ-JF
      IF(K.LT.JF) GO TO 390
      K=KK-J
      A(K1)=AK-BJ
      B(K1)=BK+AJ
      A(K2)=AK+BJ
      B(K2)=BK-AJ
      JF=JF+J
      IF(J.LT.K) GO TO 330
      KK=KK+KSPNN
      IF(KK.LE.NN) GO TO 360
      KK=KK-NN+KSPAN
      IF(KK.LE.KSPAN) GO TO 360
C
C  MULTIPLY BY ROTATION FACTOR (EXCEPT FOR FACTORS OF 2 AND 4)
C
  400 IF(I.EQ.M) GO TO 440
      KK=JC+1
  410 C2=1.0-CD
      S1=SD
  420 C1=C2
      S2=S1
      KK=KK+KSPAN
  430 AK=A(KK)
      A(KK)=C2*AK-S2*B(KK)
      B(KK)=S2*AK+C2*B(KK)
      KK=KK+KSPNN
      IF(KK.LE.NT) GO TO 430
      AK=S1*S2
      S2=S1*C2+C1*S2
      C2=C1*C2-AK
      KK=KK-NT+KSPAN
      IF(KK.LE.KSPNN) GO TO 430
```

```
      C2=C1-(CD*C1+SD*S1)                                              4200
      S1=S1+(SD*C1-CD*S1)                                              4210
      KK=KK+KSPNN+JC                                                   4220
      IF(KK.LE.KSPAN) GO TO 420                                        4230
      KK=KK-KSPAN+JC+INC                                               4240
      IF(KK.LE.JC+JC) GO TO 410                                        4250
      GO TO 200                                                        4260
C                                                                      4270
C     PERMUTE THE RESULTS TO NORMAL ORDER---DONE IN TWO STAGES         4280
C     PERMUTATION FOR SQUARE FACTORS OF N                              4290
  440 NP(1)=KS                                                         4300
      IF(KT.EQ.0) GO TO 490                                            4310
      K=KT+KT+1                                                        4320
      IF(M.LT.K) K=K-1                                                 4330
      J=1                                                              4340
      NP(K+1)=JC                                                       4350
  450 NP(J+1)=NP(J)/NFAC(J)                                            4360
      NP(K)=NP(K+1)*NFAC(J)                                            4370
      J=J+1                                                            4380
      K=K-1                                                            4390
      IF(J.LT.K) GO TO 450                                             4400
      K3=NP(K+1)                                                       4410
      KSPAN=NP(2)                                                      4420
      KK=JC+1                                                          4430
      K2=KSPAN+1                                                       4440
      J=1                                                              4450
C                                                                      4460
C     PERMUTATION FOR SINGLE-VARIATE TRANSFORM (OPTICNAL CODE)         4470
  460 AK=A(KK)                                                         4480
      A(KK)=A(K2)                                                      4490
      A(K2)=AK                                                         4500
      BK=B(KK)                                                         4510
      B(KK)=B(K2)                                                      4520
      B(K2)=BK                                                         4530
      KK=KK+INC                                                        4540
      K2=KSPAN+K2                                                      4550
      IF(K2.LT.KS) GO TO 460                                           4560
  470 K2=K2-NP(J)                                                      4570
      J=J+1                                                            4580
      K2=NP(J+1)+K2                                                    4590
      IF(K2.GT.NP(J)) GO TO 470                                        4600
      J=1                                                              4610
  480 IF(KK.LT.K2) GO TO 460                                           4620
      KK=KK+INC                                                        4630
      K2=KSPAN+K2                                                      4640
      IF(K2.LT.KS) GO TO 480                                           4650
                                                                       4660
                                                                       4670
```

```
      IF (KK.LT.KS) GO TO 470
      JC=K3
  490 IF (2*KT+1.GE.M) RETURN
      KSPNN=NP(KT+1)
C
C     PERMUTATION FOR SQUARE-FREE FACTORS OF N
C
      J=M-KT
  500 NFAC(J+1)=1
      NFAC(J)=NFAC(J)*NFAC(J+1)
      J=J-1
      IF(J.NE.KT) GO TO 500
      KT=KT+1
      NN=NFAC(KT)-1
      IF(NN.GT.MAXP) GO TO 660
      JJ=0
      GO TO 530
  510 JJ=JJ-K2
      K2=KK
      KK=K+1
      NFAC(KK)=NFAC(K)
  520 IF(JJ.GE.K2) GO TO 510
      NP(JJ)=J
      K2=NFAC(KT)
      KK=NFAC(K)
  530 J=J+1
      IF (J.LE.NN) GO TO 520
C
  540 J=0
      GO TO 550
      KK=KK-K2
      K2=NP(K)
      NP(K)=I-KK
      IF(KK.NE.J) GO TO 540
      K3=KK
      J=J+1
  550 NP(J)=NP(J)
      IF(KK.LT.0) GO TO 550
      IF(KK.EQ.J) GO TO 540
      NP(J)=KK-J
      IF(J.NE.NN) GO TO 520
      MAXF=INC*MAXF
C
C     RECORDER A AND B, FOLLOWING THE PERMUTATION CYCLES
```

```
C
  560 GO TO 620
      J=J-1
      IF (NP(J).LT.0) GO TO 560
      JJ=JC
  570 KSPAN=JJ
      IF (JJ.GT.MAXF) KSPAN=MAXF
      JJ=JJ-KSPAN
      KK=JC*KK+II+JJ
      K1=KK+KSPAN
  580 K2=KK+KSPAN+1
      AT(K2)=A(K1)
      BT(K2)=B(K1)
      K1=K1-INC
      K2=K2-1
      IF (K1.NE.KK) GO TO 580
      KK=KK+KSPAN
      KK=KSPAN*JC+(K+NP(K))
  590 K2=KK+1
      A(K1)=AT(K2)
      B(K1)=BT(K2)
      K1=K1+INC
      IF (K1.NE.KK) GO TO 590
      KK=KK+KSPAN
  600 K2=KK+1
      A(K1)=BT(K2)
      B(K1)=AT(K2)
      K1=K1+INC
      IF (K1.NE.KK) GO TO 600
      KK=KK+KSPAN
      IF (KK.NE.J) GO TO 590
  610 K=K+1
      AT(K2)
      BT(K2)
      K1=K1+INC
      K2=K2-1
      IF (K1.NE.KK) GO TO 610
      IF (INZ.NE.0) GO TO 570
      GO TO 560
  620 J=J-1
      K3=II
      IF (INT.GE.0) GO TO 560
      KSPNN
  630 N=N-1
      GO TO 10
  640 WRITE (6,650)
```

```
      650 FORMAT (' *** ERROR *** MAX PRIME FACTOR EXCEEDED')       5640
          STOP                                                     5650
C                                                                  5660
      660 WRITE (6,670)                                            5670
      670 FORMAT (' *** ERROR *** MAX PRODUCT OF SQUARE FREE VALUES EXCEED 5680
         1ED')                                                     5690
          STOP                                                     5700
C                                                                  5710
      680 WRITE (6,690)                                            5720
      690 FORMAT (' *** ERROR *** ISN CANNOT BE ZERO')             5730
          STOP                                                     5740
          END                                                      5750
```

```fortran
C   X-Y TRACKING FILTER PROGRAM DEVELOPED BY LT. G. W. MITSCHANG.
C
//    EXEC FORTCLG,REGION.FORT=170K,REGION.GO=100K
//FORT.SYSIN DD *
      DIMENSION R(6,100),FD(6,100),FDDOT(6,100),XS(100),
     1YS(100),RERROR(100),TH2(2),ARX(2),PHI(25),
     2XTAR(100),COV(25),COVK(25),BERRCR(100)
      DIMENSION ZNOISE(16),GAINTR(20),TEMPI(20)
      DIMENSION TXFILT(25),XINT(2),YINT(2)
      DIMENSION QE(4),SUBVEL(10),YMN(2),XSTD(5,20)
      DIMENSION TEMP4(4),XMN(20),RVXVY(20),VXVYA(20)
      DIMENSION HOBTR(10),SUBY(4),ST(4)
      DIMENSION TEMP3(10),XVAR(5,20),RVXY(20)
      DIMENSION SUBX(20),XYA(20),NHRAG(20)
      DIMENSION XCUR(5)
      DIMENSION HOBST(20)
      DIMENSION XYVAR(5,20),GA(4)
      COMMC(VQ,VP),FUSE,AVET
      RAG(VQ,VP,THES,AVET) = (ADELT*VQ/CTH)*SIN(THES - AVET)
      FCIT(VQ,THES,AVET) = FAVE*(1. + (VQ/VP)*COS(THES - AVET))
C
C
   59 FORMAT(///'OBSERVATIONS'//3X,'TIME',15X,'TRUE',16X,
     1'MEASURED BEARING',F10.3,6X,'+',6X,F7.3,6X,'=',9X,F10.3)
   60 FORMAT(3X,F10.3,6X,'+',6X,F7.3,6X,'=',9X,F10.3)
   61 FORMAT('USING BEARING FORMULA'//)
   62 FORMAT(3X,'SENSORS USED'/)
   63 FORMAT(5X,'MEAN',F8.2,5X,'RANGE =',F10.2,
     1'RANGE =',F8.2,5X,'ANGLES',2F10.3,5X)
   64 FORMAT(5X,F5.2,'KNOTS',5X,'ANGLES',2F10.3,5X)
   65 FORMAT(F10.3//80X,'BR NOISE STD DEV',F10.3)
   66 FORMAT('DATA',5X,'LOCATION',X =',F9.1,3X,
     1'RANGE',8X,9X,'BEARING',8X,'DOPPLER',
     29X,'Y(SUB)')
  100 FORMAT(8X,'SUBMARINE TRACK AND BOUY LOCATIONS'//',
  300 FORMAT('INITIAL GUESSES'//',HEADING IS',F8.2//)
  330 FORMAT(F6.2,'KNOTS','REST FREQ',F10.2,4X,'MED VEL',
     1'SUBMARINE VEL',F10.2//)
  401 FORMAT('BASED ON',I10,'RUNS'//)
  600 FORMAT('MONT CARLO PLOT',I10,'RUNS'//4X,'TIME POIN
     1ASIMX',VX,12X,FC//)
  701 FORMAT(X,5F15.3)
  703 FORMAT('VARIANCE',10X,5F15.3)
```

```
5005  FORMAT(//2I10)
6000  FORMAT(I4)
6001  FORMAT(4F10.2)
6002  FORMAT('  NUMBER OF RUNS PER TRACK = ',I6//)
6003  FORMAT('  NUMBER OF TRACKS = ',I6//)
8000  FORMAT('  ANGLE NOISE STD DEV IS',F8.2)
9010  FORMAT('  DETERMINENT ',E15.7)
C
666   FORMAT('  KJ =',I4,5X,'Z(KJ,1) =',F10.3,5X,'Z(1,1) =',F10.3,
     15X,'ADELTH =',F10.3)
667   FORMAT('  TIME KJ =',F10.2,5X,'Z(KJ,2) =',F10.2,5X,'Z(1,2) =',
     1F10.2,5X,'ADELF =',F10.2)
711   FORMAT('  INITIAL VELOCITY GUESS IN KNOTS',F8.1)
5010  FORMAT('  O=(',I2,') =',F10.2)
9990  FORMAT('  OSUBHD(',I2,') =',F6.1)
      PI = 3.14159
      RAD = 57.29578
C
C  IXA AND IXF ARE STARTING NUMBERS FOR RANDOM NUMBER SUBROUTINE.
C
      IXA=452323
      IXF=986521
C
C  NSPOT IS THE NUMBER OF SEPERATE TRACKS TO BE RUN. SUBX, SUBY,
C  SUBVEL, AND SUBHD ARE STARTING POSITION OF TARGET, VELOCITY AND
C  HEADING FOR THE TRACK.
C
      NSPOT=1
C
C  JJQQ IS THE NUMBER OF SIMULATIONS PER TRACK.
C
      JJQQ=100
C
C  FO IS ONLY USED TO DECIDE UP OR DOWN DOPPLER FOR HEADING CALCULATION
      FO=233.5
      WRITE(6,9959) FO
9959  FORMAT('  FO=',F8.3)
C
C  INITIAL ESTIMATE AT TARGET VELOCITY IS AVSK, IN KNOTS.
      AVSK=2.
C
C  BEARING STANDARD DEVIATION IS  5 DEGREES
C
      SA=30.
C
```

```
C
      FREQUENCY STANDARD DEVIATION IS   .025HZ
CC    SF = .025
C
      READ(5,6001) (SUBX(I),SUBY(I),SUBVEL(I),SUBHD(I),I=1,NSPOT)
      DO 204 JZA=1,5
      JZA=1
      WRITE(6,5005)  IXA,IXF
      WRITE(6,6003)  NSPOT
      WRITE(6,6001) (SUBX(I),SUBY(I),SUBVEL(I),SUBHD(I),I=1,NSPOT)
      IJK=1
      WRITE (6,9990) (J,SUBHD(J),J=1,IJK)
      WRITE(6,6002) JQQ
CCCC  TIME IS IN SECONDS
C
      NUMBER OF TIME POINTS IS NUM
      NUM=17
      TINT=60.
      DATA X(1),X(2),X(3),X(4),X(5)/0.,0.,0.,-1200.,3000./
      DATA Y(1),Y(2),Y(3),Y(4),Y(5)/0.,0.,0.,-1800.,2400./
      DT(1)=190.
      DO 9 KL=2,NUM
      DT(KL)=T(KL-1) + TINT
    9 WRITE(6,5010) (I,T(I),I=1,NUM)
C
      NUM1 = NUM + 1
CCCCCCCCC  THE SENSORS ARE POSITIONED AT X(I), Y(I).
C
C     INITIAL SUB POSITION  XSO,YSO
C
      SUB SPEED AND DIRECTION ARE VSS AND THTA
C
      XSO  = SUBX(NS)
      XXSO = SUBX(1)
      YSO  = SUBY(NS)
      YYSO = SUBY(1)
      VSS  = SUBVEL(NS)
      VVSS = SUBVEL(1)
      TXSO = T(1)
      XS(1)=XSO
      YS(1)=YSO
C
      NUMA=1
      DO 9991  NS=1,IJK
      THTA = SUBHD(NS)
      THTA = SUBHD(1)
```

```
C     CONVERT FROM DEGREES TO RADIANS
      THTAS = THTA/57.29578
C
C     CONVERT FROM KNOTS TO YARDS PER SECOND
      VS = VSS*.563
C
      FREQ = 233.85
      VMED = 1625.5
C
C     NUMBER OF OBSERVATION VARIABLES IS M.
C     THIS DETERMINES THE NUMBER OF ROWS OF HOB.
      M=2
      M1 = M - 1
      M2 = M**5
C
      WRITE(6,62) M1
C
      DO 1 I=NUMA,NUM
      XS(I) = XSO + VS*COS(THTAS)*(T(I) - TO)
      YS(I) = YSO + VS*SIN(THTAS)*(T(I) - TO)
C
C     LOOP FOR EACH HYDROPHONE
      DO 2 J=1, M1
      BR(J,I) = ((XS(I) - X(J))**2 + (YS(I) - Y(J))**2)**.5
      BRDOT(J) = ATAN((YS(I) - Y(J))/(XS(I) - X(J)))
      IF((XS(I) - X(J)).GE.0.0) GO TO 5
      IF((YS(I) - Y(J)).GE.0.0) BR(J,I) = BR(J,I) + 3.14159
      IF((YS(I) - Y(J)).LT.0.0) BR(J,I) = BR(J,I) - 3.14159
5     CONTINUE
      VRDOT(J) = VS*COS(THTAS - BR(J,I))
      FREQ(J,I) = FREQ/(1 + VR(J)/VMED)
      VRDOT(J) = (VS*SIN(THTAS - BR(J,I))*BRDOT(J,I))**2/R(J,I)
      FCDOT(J,I) = (FD(J,I)*VRDOT(J))/(FREQ*VMED)
C
C     CONVERT FROM RADIANS TO DEGREES FOR OUTPUT
      BR(J,I) = BR(J,I)*57.29578
2     CONTINUE
      XSO = XS(I)
      YSO = YS(I)
      IF(I.LT.NUM) GO TO 1
      XSO = XS(NUMA)
      YSO = YS(NUMA)
      TO=T(NUMA)
```

```
      IF (NS.EQ.IJK) TO = T(1)
9991 1 CONTINUE
      CONTINUE
C
C     OUTPUT STATEMENTS FOR BUOYS.    REMOVE COMMENT SYMBOL AS DESIRED.
C
      WRITE(6,99)
C     DO 4 L=1,M1
      WRITE(5,100) L,X(L),Y(L)
C     DO 4 K=1,NUM
      WRITE(6,200) T(K),R(L,K),BR(L,K),FD(L,K),FDDOT(L,K),XS(K),YS(K)
    4 CONTINUE
C
C
C     SET OF PARAMETERS FOR CALL GAUSS SUBROUTINE
C
C
      WRITE(6,8000) SA
      AMA = 0.

      AMF     = 0.
      DO 398 IY=1,20
      ZHOLD(IY)=0.
      DO 399 IX=1,5
      XMC(IX,IY) = 0.
      XYVAR(IX,IY) = 0.
      XMX(IX,IY)=0.
  399 CONTINUE
      XINT(2) = 0.
      YINT(2) = 0.
      YINVE   = 0.
  398 CONTINUE
      DO 397 JJ=1,20
      RXY(JJ) = 0.
      XYA(JJ) = 0.
      RVXVY(JJ) = 0.
      VXVY4(JJ) = 0.
  397 CONTINUE
      AVKJ = 0.
      WRITE(6,400) VSS,THTA
      WRITE(6,711) AVSK
C     THIS DO LOOP RUNS JJQQ SIMULATIONS PER TRACK.
C
C
C     SET MEASUREMENT MATRIX Z TO ZERO.
C
```

```
      DO 44 JZ=1,100
      DO 44 KZ=1,5
      Z(JZ,KZ) = 0.0
44    AVEVA = 0.0
      WRITE (6,1092)
      CCVXX = 00.00
      CCVYY = 00.00
C
C     Z(X,2) = FREQ INFO
C
      READ (5,56) (Z(J,2),J=1,NUM)
      WRITE (6,58)
58    FORMAT ('0INPUT FREQUENCY DATA')
      WRITE (6,56) (Z(J,2),J=1,NUM)
56    FORMAT (6(F10.3))
C
C     Z(X,1) = BEARING INFO
C
      DO 9971 I=1,NUM
      ZHOLD(I) = Z(I,2)
9971  CONTINUE
      NUMZ=NUM
      DO 206 KIKM=1,3
      IF(KIKM.EQ.2) AVSK=4.5
      IF(KIKM.EQ.3) AVSK=7.0
      DO 201 JQ=1,JJQQ
      NUM=NUMZ
      DO 9972 I=1,NUMZ
      Z(I,2)=ZHOLD(I)
9972  CONTINUE
      IREI=0
      DATA F(1),F(2),F(3)/0.,0.,0./
      WRITE(6,59)
C
C     SIMULATE BUOY MEASUREMENTS.
C
      DO 50 K=1,NUM
      CALL GAUSS(IXA,SA,AMA,VA)
      AVEVA = AVEVA + VA
      VARVA = VARVA + VA**2
      Z(K,1) = BR(1,K) + VA
50    CONTINUE
C     ESTIMATE OF SOUND VELOCITY IS VP.
      VP=1625.5
```

```fortran
C     KALMAN FILTER LINEAR STATES USING  X,Y COORDINATES
C     WITH NON-LINEAR MEASUREMENT MATRIX  AND STATE DEPENDENT
C     EXCITATION

C     CLEAR ALL MATRICES TO ZERO.
      DO 11 JJ=1,25
      CCV(JJ)    = 0.
      CCVK(JJ)   = 0.
      PHIT(JJ)   = 0.
      PHITK(JJ)  = 0.
      QERRKR(JJ) = 0.
      RERRKR(JJ) = 0.
      BERRKR(JJ) = 0.
      TEMP4(JJ)  = 0.
   11 CONTINUE
      DO 12 JJ=1,20
      GAIN(JJ)   = 0.
      GGINTR(JJ) = 0.
      HOBTR(JJ)  = 0.
      TEMP1(JJ)  = 0.
      TEMP2(JJ)  = 0.
      TEMP5(JJ)  = 0.
   12 CONTINUE

      DO 92 I=1,16
   92 ZNOIS(I) = 0.

C     BEARING STANDARD DEVIATION IS SQ RT OF ZNOIS(1)   (IN RADIANS)
      ZNOIS(1) = (SA/57.2957S)**2
C     FREQUENCY STANDARD DEVIATION IS SQ RT OF ZNOIS(4)
      ZNOIS(M+2) = SF**2
      ZNOIS(MM)  = SF**2
      IF(M.EQ.4) ZNOIS(11) = ZNOIS(MM)
C
      WRITE(6,1058)
      DO 96 LP=1,M
      LPB=LP*M
      WRITE(6,1059) (ZNOIS(KB),KB=LPB,LPE)
   96 LPE = LPE + 1
```

```
C     X(1)  =  X COORDINATE
C     X(2)  =  XY VELOCITY
C     X(3)  =  Y COORDINATE
C     X(4)  =  Y VELOCITY
C     X(5)  =  REST FREQ, FO.
C
C     ALL DIMENSIONS ARE GIVEN IN YARDS
C
C     1 KNOT  =  .563  YARDS / SEC.
C
C     MATRICES ARE STORED COLUMN BY COLUMN
C
C     TO WRITE OUT MATRICES ROW BY ROW THE TRANSPOSE MUST BE WRITTEN
C     SINCE THE STORAGE IN MEMORY IS BY COLUMN
C
      AVS = AVSK*.563
C
C     CALCULATION OF THE INITAL CONDITIONS FOR THE FILTER.
C
C     TO INITIALIZE THE FILTER THE TWO BEARING MEASUREMENTS MUST
C     BE GREATER THAN 3 STD DEV OF THE NOISE APART.
C
      IABC=0
      KJ = 1
90    Z(KJ,1) = Z(1,1)
      IH = IH+KJ
      IABC=(NUM+IABC) GO TO 939
      IF(ABS(ADELTH).LT.(3.*SA)) GO TO 90
939   CONTINUE
      DELF = T(KJ) - T(1)
      DELF = (T(KJ) + T(1))/2.
      AVKJ = (Z(KJ,2) + Z(1,2))
      IF(DELF.GE.0.01) GO TO 90
      AVKJ=0.01/JJQQ + AVKJ
      ATRUE=0.
      IH=(6,666) KJ, Z(KJ,1),Z(1,1),ADELTH
      ARKJ=(6,2,2)/KJ + ATHETH
      WRITE(6,667) KJ,Z(KJ,2),Z(1,2),ADELF,ATHETH
      OUT=(Z4,12.2)+(XS(KJ).2+Z(1,2).2)**2 + ((YS(KJ)) + YS(1))/2.)**2)**.5
      ASINE = XS(KJ)/(ADELTH/57.29578)*Z(KJ,2)*AVS)
      ASINE = (ADELF*VP/((ADELTH/57.29578)*Z(KJ,2)*AVS)
      WRITE(6,668) ASINE
      IF(ABS(ASINE).LE.1.) GO TO 91
C
C     INITIAL SPEED ESTIMATE MUST BE TOO SLOW, INCREASE BY 2 KNTS.
C
      AVS = AVS + 2.*.563
```

107

```
         GO TO 95
   91    HDT=(ARSIN(ASINE))*57.29578
         IF(Z(N,2).LE.F0) HDING =ATHETH + HDT
         IF(Z(N,2).GT.F0) HDING = ATHETH - HDT
         IF(HDING.GT.180.) HDING = HDING - 360.
         IF(HDING.LT.-180.) HDING = HDING + 360.
         AVTHR  = ATHETH/RAD
         HDDR   = ADELTH/RAD
         DELTHR = RNG(AVS,DELTHR,HDDR,AVTHR)
         ARHALF = Z(1,2)
C
C        ESTIMATE OF BEST FREQUENCY.
C
         FAVE = 0.
         DO 94 NJ=1,KJ
   94    FAVE = FAVE + Z(NJ,2)/KJ
         FCI(AVS,HDDR,AVTHR)
         IF(M.EQ.2) GO TO 944
C
C        ESTIMATION OF RANGE USING SECOND BUOY FREQ DATA.
C
  941    F2AVE = (Z(KJ,3) + Z(1,3))/2.
         COTEM = (VP/AVS)*(F0/F2AVE - 1.)
C
C        ADJUST F0 IF ABS(COTEM) IS GREATER THAN 1.
C
         IF(COTEM.LT.-1.) F0 = F0 + .05
         IF(COTEM.GT.+1.) F0 = F0 - .05
         IF(ABS(COTEM).GT.1.) GO TO 941
         ANTEM = ARCOS(COTEM)*57.29578
C
C        TWO POSSIBLE BEARINGS TO THE SECOND BUOY.
C
  942    HDING  = ANTEM
         HDING  = -ANTEM
         T2(2) = ((X(2) - Y(1))**2 + (Y(2) - Y(1))**2)**.5
         IF(X(2)-X(1).GT.00.) GO TO 942
         T2 = T2 + 180.
         T2 = T2 - 180.
         XI = ATHETH/RAD
         TH2(2) = T2/TAN(KA)/RAD
         TH2(2) = T2/TAN(KA)/RAD
         DU = 2DU./(SIN(TIDF)/TAN(T2DF))
  943    ARX(KA) = D2/TAN(T2DF)
         IF(ABS(ARX(1)).LT.ABS(ARX(2)) - ARHALF)) ARHALF = ARX(1)
         IF(ABS(ARX(2)).LT.ABS(ARX(1)) - ARHALF)) ARHALF = ARX(2)
```

108

```
  944 CONTINUE
      XCUR(2)= AVS*COS(HDING/57.29578)
      XCUR(4)= AVS*SIN(HDING/57.29578)
      XXCUR(3)= ARHALF*COS(ATHETH/57.29578)
      XXCUR(5)= ARHALF*SIN(ATHETH/57.29578)
      XXCUR(1)= FO
      XXXCUR(3)= XCUR(1)/1000.
      XXXCUR(5)= XCUR(3)/1000.
      XXXY=XCUR(1)+XINT(1)+YINT(1)
      XXXY=XCUR(3)+XINT(1)**2*XINT(2)
      XXXY=XINT(1)+XINT(1)**2/ XINVEU
      XY=XINT(6,708)XINVY
      XY=XINT(6,21)COS(THETAS)
      OVY=XY**SIN(THETAS)
      WRITE(6,708)ARHALF,ARTRUE,XCUR(2),OVX,XCUR(4),OVY
      WRITE(6,21)ATHETH,HDT,HDING,FO
      ARHALF=ARHALF/1000.

C     STANDARD DEVIATION OF INITIAL VELOCITY ASSUMED TO BE 3 KNOTS
C                 (1.7 YDS/SEC)

      ATHETH= ATHETH/RAD
      ADELTH= ADELTH/RAD
      ADELJ= ADELTH/1000.
      AK= FLOAT(KJ)

C     DIAGONAL INITIAL COVARIANCE IF M GE 3

      DCCUR(1)= 4.00
      DCVK(17)= 4.00
      DCVK(19)= 2.00
      DCVK(25)= 1.00
      IF(M.GE.3)GO TO 149

C     INITIAL COVARIANCE MATRIX

      CST= COS(ATHETH)
      SN= SIN(ATHETH)
      SA= .41442*SA/RAD
      AV=.41442*SQRT(AK)/RAD
      ADA= ADELTH+AA
      ADELFF= ADELTH-AA
      HDA= ADELTH+ADELFF,ADELTH,AVS,ATHETH)
      HUA= ADELTH+ADELFF,AVS,ATHETH)
```

```
      HCA  = HEAD(ADELF,ADELTH-AA,AVS,ATHETH)
      HUV  = HEAD(ADELF,ADELTH,AVS+VV,ATHETH)
      HDF  = HEAD(ADELF,ADELTH-VV,ATHETH)
      XUF  = RNG(AVS,ADELTH,HUF,ATHETH)*CST
      SGXA = RNG(AVS,ADELTH+AA,HJA,ATHETH)*CST
      XDA  = RNG(AVS,ADELTH,AA,HDA,ATHETH)*CST
      XDV  = RNG(XDV,ADELTH,HUV,HDV,ATHETH)*CST
      SGXV = RNG(AVS,ADELTH,HDV,ATHETH)*CST
      XDT  = RNG(XDT,ADELTH(ATHETH+AVAV)
      SGXT = ARHALF*XDT(ATHETH-AVAV)
      SGYA = SGXA*SIN(ATHETH,AVAV)
      YCT  = COS(YDU)+COS(ATHETH-AVAV)
      SGYV = SNT*COS(HUF)-COS(HDF))
      SGYT = SNT*COS(HUA)-COS(HDA))
      SGFF = YDU*SIN(HUF)-SIN(HDF))
      CCVK(7)  = YOU+(SIN(HUA)-SIN(HDA))
      CCVK(13) = COS+(AVS-VV)*COS(HDV))
      CCVK(25) = SIN+(AVS-VV)*SIN(HDV))
                 FOIT(AVS,HDA,ATHETH))
                 FOIT(AVS,+DF,ATHETH))
                 FOIT(AVS-VV,HDV,ATHETH))
                 FOIT(AVS-VV,HDA,ATHETH))
      SGXF**2 + SGXV**2 + SGXT**2
      SGYF**2 + SGYA**2 + SGYV**2 + SGYT**2
      SGFF**2 + SGFA**2 + SGFV**2

C     SET NC = 1 IF ONLY DIAGONAL TERMS ARE WANTED

      NC = 0
      IF(NO.EQ.1) GO TO 149

      CCVK(2) = SGXF*SGVXF + SGXA*SGVXA + SGXV*SGVXV
      CCVK(3) = SGXF*SGVYF + SGXA*SGVYA + SGXV*SGVYV + SGXT*SGYT
      CCVK(4) = SGXF*SGVFF + SGXA*SGVYA + SGXV*SGVYV
      CCVK(5) = SGXF*SGFF + SGXA*SGFA + SGXV*SGFV
      CCVK(8) = SGYF*SGYF + SGVXA*SGYA + SGVXV*SGYV
      CCVK(9) = SGVXF*SGVYF + SGVXA*SGVYA + SGVXV*SGVYV
```

110

```fortran
      CCVK(10) = SGVXF*SGFF + SGVXA*SGFA + SGVXV*SGFV
      CCVK(11) = CCVK(3)
      CCVK(12) = CCVK(8)
      CCVK(15) = SGVYF*SGFF + SGVYA*SGFA + SGVYV*SGFV
      CCVK(16) = SGYF*SGFF + SGYA*SGFA + SGYV*SGFV
      CCVK(17) = CCVK(4)
      CCVK(18) = CCVK(9)
      CCVK(20) = CCVK(14)
      CCVK(21) = SGVYV*SGFF + SGVYA*SGFA + SGVYV*SGFV
      CCVK(22) = CCVK(5)
      CCVK(23) = CCVK(10)
      CCVK(23) = CCVK(15)
      CCVK(24) = CCVK(20)
  149 CONTINUE
      WRITE(6,1061) CCVK
C
C     PARAMETERS FOR EXCITATION MATRIX     SIGTH  =  HEADING STD DEV.
C                                          SIGVS  =  VELOCITY STD DEV.
C     COEF SQUARED FOR VARIANCE            SIGFO  -  REST FREQ STD DEV.
C
      SIGTH = 10. DEGREES/100. SEC
      SIGTH = 3.04
      SIGVS = 1 KNOT/100. SEC
      SIGVS = 31.7
      SIGFO = 1 HZ/100. SEC
      SIGFO = 1.0
C
C     LOOP FOR MEASUREMENT DATA
C
      TT = (T(1) - ATHALF)/1000.
      DO 200 LL=1,NUM
      IF(LL.EQ.1) GO TO 88
      TT=(T(LL)-T(LL-1))/1000.
C
C     PUT IN PHI MATRIX
C
   88 PHI(1,1) = 1.
      CALL GMTRA(PHI,PHITR,5,5)
      WRITE(6,1600) T(LL)
C
```

111

```fortran
      WRITE(6,1001) PHITR
      XPRED=PHI*XCUR
      CALL GMPRD(PHI,XCUR,XPRED,5,5,1)

C     CALCULATE PREDICTED COVARIANCE MATRIX
C     NEED POSITIVE VALUES IN PHI MATRIX FOR COVARIANCE UPDATE.
      PHI(6) = ABS(TT)
      PHI(18) = ABS(TT)
      PHI(2) = PHI(6)
      PHI(14) = PHI(18)

C     CALCULATION OF THE STATE EXCITATION MATRIX.  IT IS STATE DEPENDENT.
      VSX = XCUR(2)**2
      VSX = (XCUR(2)/VSX)*SIGVS + (XCUR(4)**2)*SIGTH
      BX = XCUR(2)*XCUR(4)*(SIGVS/VSX - SIGTH)
      CX = (XCUR(4)**2/VSX)*SIGVS + (XCUR(2)**2)*SIGTH
      Q(1) = AX*.25*TT**4
      Q(2) = BX*.25*TT**4
      Q(4) = BX*.5*TT**3
      Q(6) = QEXIT(3)
      Q(7) = QEXIT(4)
      Q(8) = QEXIT(2)
      Q(9) = BX*.5*TT**3
      Q(12) = QEXIT(4)
      Q(13) = CX*.25*TT**4
      Q(14) = QEXIT(9)
      Q(16) = CX*.25*TT**4
      Q(17) = QEXIT(14)
      Q(18) = QEXIT(19)
      Q(19) = QCX*.5*TT**3
      Q(25) = SIGTH*TT

      COVK = PKK
      COVK = PKKM1
      CALL GMPRD(PHI,COVK,TEMP4,5,5,5)
      CALL GMPRD(TEMP4,PHITR,TEMP5,5,5,5)
      DO 7 JJ=1,25
    7 COV(JJ)=TEMP5(JJ) + QEXIT(JJ)
      WRITE(6,1050) QEXIT
      WRITE(6,1060) COV

C     LINEARIZED OBSERVATION MATRIX (TRANSPOSE)
      HOBTR(1) = HOBTR(5)    ANGLE
      HOBTR(6) = HOBTR(10)   FREQ(1)
```

```
C
C         HOBTR(11) - HOBTR(15)      FREQ(2)
C
C         PREDICTED BEARING IS H1.
C
9975  IF(XPRED(1).GT.0.) GO TO 9975
      IF(XPRED(3).GE.0.) H1=PI
      IF(XPRED(3).LT.0.) H1=-PI
      GO TO 45
      H1=ATAN(XPRED(3)/XPRED(1))
      IF(XPRED(1).GT.0.) GO TO 45
      IF(XPRED(3).GE.0.) H1 = H1 + 3.14159
      IF(XPRED(3).LT.0.) H1 = H1 - 3.14159
45    CONTINUE
C
      DO 46  N=1,M1
      NN = 5*XPRED(1)
      XDIS = XPRED(1) - X(N)/1000.
      YDIS = XPRED(3) - Y(N)/1000.
      XYSQ(N) = XDIS**2 + YDIS**2
      F(N) = XPRED(5)*VP/(VP +((XPRED(2)*XDIS + XPRED(4)*YDIS)/(XYSQ(N)*
     1*.5))*XPRED(5))
      HOBTR(NN+1) = (XPRED(5)*VP)
      HOBTR(NN+2) = (A*YDIS)/(XYSQ(N)**.5
      HOBTR(NN+3) = -XDIS/XYSQ(N)
      HOBTR(NN+4) = (A*XDIS/XYSQ(N+1)**XDIS/YDIS
      HOBTR(NN+5) = F(N)/XPRED(5)
      HOBTR(NN+2) = -XPRED(3)/XYSQ(1)
      HOBTR(NN+3) = XPRED(1)/XYSQ(1)
      HOBTR(NN+4) = 0.
      CALL GMTRA(HOBTR,HOB,5,M)
      WRITE(6,1020)(HOBTR(K),K=1,M2)
46    CONTINUE
C
C     CALCULATE THE GAIN MATRIX
C
      CALL GMPRD(CCV,HOBTR,TEMP1,5,5,M)
      CALL GMPRD(HOB,TEMP1,TEMP2,M,5,M)
22    TEMP2(JJ) = TEMP2(JJ) + ZNOIS(JJ)
      CALL MINV(TEMP2,M,D,LT,WM)
      WRITE(6,9010)(TEMP1,TEMP2,GAIN,5,M,M)
      CALL GMPRD(TEMP1,TEMP2,GAIN,5,M,M)
      CALL GAIN(1)=GAIN(1)
      CALL GMTRA(GAIN,GAINTR,5,M)
C
```

113

```
C
      WRITE (6,1039)
      DO 47 I=1,5
      IE = M*I
      IB = IE + 1
   47 WRITE(6,1040) (GAINTR(MG),MG=IB,IE)
      IB = IE + 1
C
C     UPDATE THE COVARIANCE MATRIX
C
      CALL GMPRD(GAIN,HOB,TEMP4,5,M,5)
      DO 3 JJ=1,25
    3 TEMP4(JJ) = -TEMP4(JJ)
      DO 444 JJ=1,25,6
  444 TEMP4(JJ) = 1. + TEMP4(JJ)
      CALL GMPRD(TEMP4,COV,COVK,5,5,5)
      WRITE(6,1070) COVK
C
C     CALCULATE RESIDUAL BASED ON ESTIMATED VALUE OF THE OBSERVATIONS
C     AND THE INPUT MEASUREMENT
C
      HH1=57.29578
      Z(LL) = HH1*...
      IF(RESA.GT.180.) RESA = RESA + 360.
      IF(RESA.GT.180.) RESA = RESA - 360.
      F(1) = IRE + 1
      F(2) = IRE+ 1
      Z(LL) = F(3,J,J=1,M)
      HH1 = F(3,J,J=1,M1)
      RESF2 = 0.
      RESF3 = 0.
      WRITE(6,2010) RESA,RESF1,RESF2,RESF3
C
      RESA = RESA/57.29578
    6 GAIN(J)=XPRED(J)+GAIN(J)*RESA + GAIN(J+5)*RESF1+GAIN(J+10)*RESF2
     1         + GAIN(J+15)*RESF3
      FREQ = ...
      XMC(J,LL) = ...
      XFIL(J) = ... + XVAR(J,LL)
      XVAR(J) = XVAR(J)**2 + XVAR(J,LL)
      XFIL(5) = FREQ
      XFIL(1) = XFIL(3) + XYVAR(1,LL)
      XVAR(2,LL) = XFIL(2)*1000.
      XTAR(LL) = XFIL(4) + XYVAR(2,LL)
      YTAR(LL) = XFIL(3)*1000.
```

114

```
      BTEMP = (ATAN(XFIL(3)/XFIL(1)))*57.29578
      IF(XFIL(1).GT.0.) GO TO 49
      IF(XFIL(3).GE.0.) BTEMP = BTEMP + 180.
      IF(XFIL(3).LT.0.) BTEMP = BTEMP - 180.
   49 CONTINUE
      RTEMP = ((XS(LL) -XFIL(1))**2 + (YS(LL) -XFIL(3))**2)**.5
      RTEMP = RTEMP*1000.
      BR(1,LL) = BTEMP
      ERROR(LL) = (XFIL(2)**2 + XFIL(4)**2)**.5
      VSFIL = (XFIL(2)**2 + XFIL(4)**2)**.5
      VSFIL = VSFIL/.563
      HDFIL = (ATAN(XFIL(4)/XFIL(2))*57.29578
      IF(XFIL(2).GT.0.) GO TO 48
      IF(XFIL(4).GE.0.) HDFIL = HDFIL + 180.
      IF(XFIL(4).LT.0.) HDFIL = HDFIL - 180.
   48 CONTINUE
 1080 FORMAT(...)
      WRITE(6,1080) XCUR,XPRED,XFIL
      COVXX = COVXX/1000./1000.
      COVXY = COVXY/1000.
      WRITE(6,1081) XXS,XSL,COVX,YSL,OVY,FREQ
C     WRITE(6,1082) VSFIL,HDFIL
      LL = LL + 1
 1094 CONTINUE
      XK = XFIL(KK)
 1091 WRITE(6,1093) RTEMP,BTEMP,R(1,LL),BR(1,LL)
      COVXX = COVK(1)/JJQQ + COVXX
      COVXY = COVK(3)/JJQQ + COVXY
      COVYY = COVK(15)/JJQQ + COVYY
  657 FORMAT(' ...OF GAIN(1)  VRS TIME POINTS')
      WRITE(6,657) GAIN,0)
C     PLOT XFIL,IRE
      CALL PLOT(X,Y,-5,1)
      CALL PTP(XINT,YINT,2,2)
      CALL PTP(XS,YS,NUM,2)
      CALL PTP(XTAR,YTAR,NUM,3)
      DO 203 J=1,NUM
      DO 202 L=1,5
  202 XMC(J,LL) = XMC(J,LL)/JJQQ
      CONTINUE
      XMC(5,LL) = XMC(5,LL) + FREQ
      XMC(1,LL) = XMC(1,LL)*1000.
      XMC(3,LL) = XMC(3,LL)*1000.
  203 WRITE(6,700) JJQQ
```

115

```
9977  WRITE (6,9977) FC,AVSK,SF,SA
      FORMAT('0FC=',F6.1,2X,'AVSK=',F4.1,2X,'SF=',F6.3,
     .2X,'SA=',F5.1)
C
      XINT(1) = 0.
      XINT(1) = 0.
      XINT(2) = XINT(2)/JJQQ
      YINT(2) = YINT(2)/JJQQ
      XINT(2) = XINT(2)/JJQQ
      YINT(2) = YINT(2)/JJQQ
      XINT(2) = XINT(2)/JJQQ
      CALL DPLOTP(XINT,YINT,5,1)
      CALL PLOTP(XINT,Y,5,1)
      CALL PLOTP(XS,YS,NUMZ,2)
      CALL PLOTP(XMN,YMN,NUM,3)
204   CONTINUE
206   CONTINUE
      END
      FUNCTION HEAD(DF,VS,AV)
10    FORMAT(F15.4)
      COMMON FQ,VP,FO,PI,RAD
      VP=FQ*DF/RAD
8001  WRITE(6,3001) DF,VS,AV,FQ,VP,FC,PI,RAD
      ASINE=FQ*DF/(FQ*DT*VS)
10    IF(ASINE.GT.1.) ASINE = 1.
      IF(ASINE.LT.-1.) ASINE =-1.
      ASIN=ARSIN(ASINE)
      H = ARSIN(ASINE) + ARSIN(ASINE)
      IF(CH.GT.0) H = H - 2.*PI
      IF(CH.LT.PI) H = H + 2.*PI
      RETURN
      END
C
C
```

116

BIBLIOGRAPHY

1. Mitschang, G. W., An Application of Nonlinear Filtering Theory to Passive Target Location and Tracking, Ph.D. Thesis, Naval Postgraduate School, June 1974.

2. Coppens, A. B., Sound in the Ocean, unpublished notes presented in PH3452, p. 1, Naval Postgraduate School, November 1973.

3. Arfman, J. F., Jr., A Software Package for Analysis of Geophysical Measurements, M.S. Thesis, Naval Postgraduate School, June 1971.

4. Urick, R. J., Principals of Underwater Sound for Engineers, pp. 264-266, McGraw-Hill, 1967.

5. Coppens, A. B., The Sonar Equations, unpublished notes presented in PH3452, p. 14, Naval Postgraduate School, November 1973.

6. Singleton, R. C., "An Algorithm for Computing the Mixed Radix Fast Fourier Transform," Transactions on Audio and Electro-acoustics, V. AU-17, No. 2, pp. 93-103, June 1969.

INITIAL DISTRIBUTION LIST

No. Copies

1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Department Chairman, Code 52 Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	2
4.	Professor H. A. Titus, Code 52Ts Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	10
5.	Naval Security Group Command Attn: G80 3801 Nebraska Ave. Washington, D.C. 20390	2
6.	Asst. Professor D. E. Kirk, Code 52Ki Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
7.	Asst. Professor J. E. Ohlson, Code 5201 Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
8.	Naval Security Group Command Attn: LT George W. Mitschang, USN 1301 Nebraska Ave. Washington, D.C. 20390	1
9.	Staff, Commander Patrol Wings U. S. Atlantic Fleet Attn: LT Dennis W. Hurst, USN Naval Air Station Brunswick, ME. 04011	1